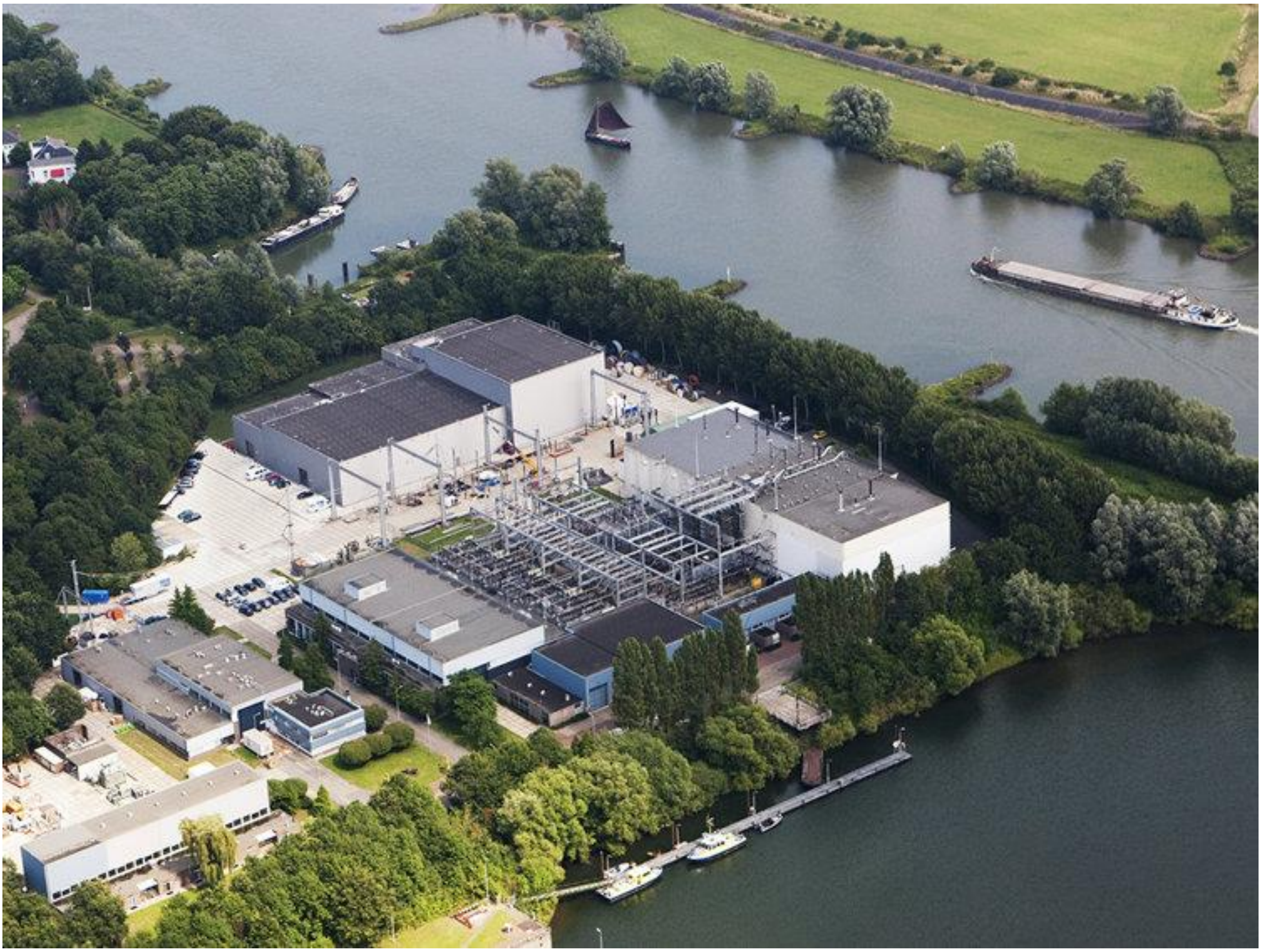


Designing a dike using a semi-probabilistic design method

Bachelor Thesis

Ellen Daamen

1 July 2016

This is the bachelor thesis of Ellen Daamen, s1485873.
The bachelor thesis is the final assessment in order to complete the bachelor study Civil Engineering of the University of Twente. During this bachelor thesis the student has to show that she has sufficient substantive knowledge and can work and report systematically. The bachelor thesis is performed at an external company in order to see if the student can put the gained knowledge into practice. The research for the bachelor thesis is performed at Witteveen+Bos in Deventer.

The research and the report of the bachelor thesis are performed under guidance of;

MSc. John Damen

UNIVERSITY OF TWENTE.

Ir. Joost Lansink

Witteveen+Bos

Preface

With the bachelor thesis the bachelor program of civil engineering will be completed. For the bachelor thesis there was a 10-week internship at an external company. I performed my bachelor thesis at Witteveen+Bos in Deventer at the department of deltas, coastal areas and rivers.

For my bachelor thesis I was looking for a practical research in which I put my knowledge into practice. In my application letter I wrote that I was looking for a research with respect to rivers and dikes, that I used to be around the Lower Rhine in Oosterbeek in my childhood and that I was there often during the weekends and in holidays at our sailboat. When I heard that Witteveen+Bos had a project for me about KEMA Laboratories that was located in Arnhem near the Lower Rhine, I was very excited. The location of the subject of my thesis was located two kilometers upstream of the location where I spend most of my childhood holidays. I was familiar with the research location of my thesis so it was for me much easier to do the research and relate to its surroundings. For me the bachelor thesis was a very educational experience. I learned a lot about the new programs, the design methods for dikes and how it worked at an engineering agency.

During my thesis I was guided by Ir. Joost Lansink of Witteveen+Bos and MSc. John Damen of the University of Twente. I want to thank them for their help and feedback during my thesis. I also want to thank my colleagues at Witteveen+Bos, Reza Hussaini and Joost Noordermeer, who helped me during my thesis and could always make time to help and explain.

Deventer, July 2016

Ellen Daamen

Table of contents

Abstract

KEMA Laboratories is located near the Lower Rhine in Arnhem. For a future expansion all risks have been identified. KEMA Laboratories is located near the Lower Rhine, outside the primary flood defenses. One of the potential risks of the area around KEMA Laboratories is flooding. In order to make sure that the area around KEMA Laboratories does not get flooded, a dike will be designed for this location. Witteveen+Bos created in an earlier research a temporary solution for this problem. They created an emergency plan with big bags and sand bags that can be placed if high water is expected. The emergency plan that Witteveen+Bos created is based on the former philosophy of probability of exceedance. The emergency plan also has the disadvantages that it is a temporary solution and that it has to be practiced regularly. For the bachelor thesis the option is researched to replace this temporary solution with a structural solution. A dike is designed using a semi-probabilistic design method, which is the most recent method for the designing and testing of flood defenses. The semi-probabilistic design method is still in development, but the government aims to implement this new method in 2017. A probabilistic design approach aims to determine the probability of flooding and to judge its acceptability in terms of the consequences. The dike designs in this research are made according to a semi-probabilistic design method. It is not possible yet to make a dike design with a fully probabilistic design method.

The research aim of the bachelor thesis is to design a dike for KEMA Laboratories near the Lower Rhine by using a semi-probabilistic design method. The main research question that will be answered is: What dike design scores best on the given requirements and boundary conditions using a semi-probabilistic design method? To answer this question first all requirements and boundary conditions are established. The boundary conditions are divided into five categories: the wishes and requirements of KEMA Laboratories, the hydraulic boundary conditions, the geometric boundary conditions, the geotechnical boundary conditions and the geo-hydrological boundary conditions. With the requirements and boundary conditions calculations have been made for the failure mechanisms height, piping and macro stability. The output of these calculations determines the properties of the dike designs. In total there are six dike designs are established as a possible solution. There are three possible locations for the dike designs: completely around the foreland, on the foreland but with room outside the dike or completely on the terrain of KEMA Laboratories. The dike can be made in two types of materials: clay or sand with a top layer of clay. In consultation with the department for cost calculation of Witteveen+Bos the construction costs of the dike designs have been determined. In order to determine the best dike design for KEMA Laboratories, the designs are compared in a multi-criteria analysis. In the multi-criteria analysis the following criteria have been taken into account: costs, impact on the terrain of KEMA Laboratories, extensibility, sustainability and sensitivity for the failure mechanisms. Based on these criteria a sand dike located completely on the terrain of KEMA Laboratories has been chosen as the best option for the construction of a dike. This option scored best on the criteria costs, sustainability and sensitivity for the failure mechanisms. In comparison to the original emergency plan designed by Witteveen+Bos this option is a good alternative. For a respectively low costs a dike can be constructed that is designed according to the most recent legislation and that satisfies all boundary conditions and requirements.

1. Introduction

1.1 Current situation

KEMA Laboratories is located in Arnhem near the Lower Rhine. The KEMA High-Power Laboratory in Arnhem provides a short-circuit, switching and mechanical testing and certification to utilities and equipment manufacturers worldwide (DNV GL, 2016). The laboratory is part of the DNV GL group that is a worldwide classification society in particular for the energy, maritime, oil & gas industry. DNV GL will build an expansion of the High-Power Laboratory in Arnhem. As is shown in Figure 1 KEMA Laboratories is located near the Lower Rhine. The ground level at the location is between 13.90m +NAP and 14.15m +NAP. KEMA Laboratories is located at an area outside the dikes near kilometer marker 886. The area of the KEMA is not located within a dike ring. It is situated across from dike ring 43-3 and in the extension of dike ring 47-1, as is shown in Figure 2. The location is outside the primary flood defenses, but the laboratories are located on formal high ground. For the expansion of KEMA Laboratories all potential risks have been identified. Since KEMA Laboratories is located near the Lower Rhine, there is a risk of flooding. In an earlier research Witteveen+Bos created an emergency plan for this location with big bags and sand bags that can be placed at the location of KEMA Laboratories if a high water level is predicted.

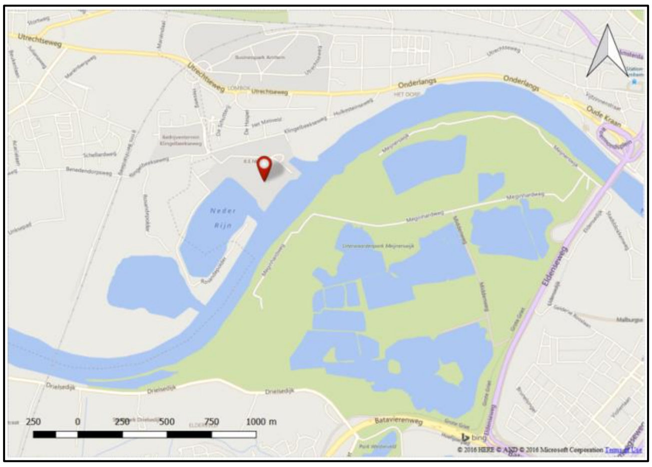


Figure 1: Location of KEMA Laboratories (Bing Maps, 2016)

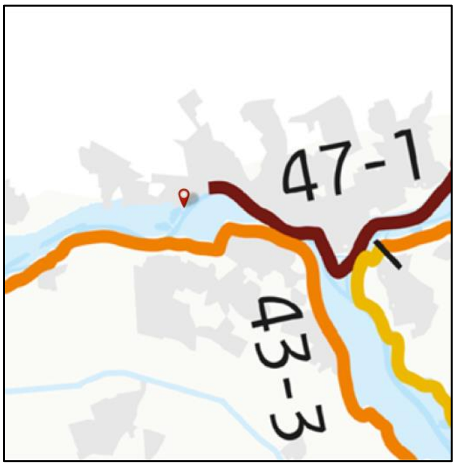


Figure 2: Location of KEMA Laboratories with respect to dike rings (Deltacommissaris, 2014)

1.2 Problem definition

The emergency plan that Witteveen+Bos created is based on the former philosophy of probability of exceedance. Besides this the emergency plan has the disadvantages that it is a temporary solution and that it has to be practiced regularly. For the bachelor thesis the option will be researched to replace this temporary solution with a more structural solution. In order to comply in the future with the recent insights and legislation for probabilistic designs, the dike designs will be made using a semi-probabilistic design method. This is the most recent method for testing and designing water-retaining structures. The semi-probabilistic design method is still in development, but the government aims to implement this new method in 2017.

1.3 Context

The Netherlands has a land area of 42.000m^2 and about 17 million inhabitants. About 50 per cent of the Netherlands is below sea level. This land is protected from flooding by dunes and dikes that stands between the land and the water. Although the east side of the Netherlands is located on higher ground, much of this land is protected from river floods by dikes. Safety from flooding is provided by 53 dike rings, which protect the land areas behind the dikes. (Walker, et al., 1994)

History of dike design

In the middle ages dikes were designed at the highest known storm plus one meter additional freeboard. This practice was not possible anymore since the construction of the Afsluitdijk, because there was no data available about the storms at this location. After the flood disaster in 1953, storm surge levels were approached statistically and extrapolated storm surge levels were then used for dike designs. Since the 1980s engineers started to use probabilistic methods for dike designs (Vrijling, 2000).

In the Netherlands the design of dikes and other water retaining structures were based on an acceptable probability of overtopping. The designs were based on an average return period of exceeding a certain water height at each dike section. There are four safety classes for the acceptable average return periods of 1.250, 2.000, 4.000 and 10.000 years. This method for designing dikes stems from a time when only the water levels were considered to be a statistical quantity and overtopping of the dike was considered the most dangerous failure mechanism (Van Manen & Brinkhuis, 2005).

Flood risk

Since the 1980s the awareness grew that the probability of exceedance of the design water level is not a good predictor of the probability of flooding. Some parts of the dike may already be critically loaded before the design water level is reached. Dikes can also fail because of macro instability, in which a part of the dike slides off, or piping, when water can flow through the sand layer under the dike and causes the dike to fail. Also the length of the dike ring has influence on the on the flood risk of the dike. A single weak spot determines the actual safety of the dike, since a chain is as strong as the weakest link (Vrijling, 2000).
Because of the shortcomings of the old design method, the Dutch Government wants to change the acceptable maximum frequencies of overtopping to a new system that sets limits to a maximum allowed risk. Risk is in this case defined as the probability multiplied by the consequences, where the consequences consist of material damage, victims, environmental and cultural damage (Van Manen & Brinkhuis, 2005).

Probabilistic design method

The probabilistic design approach aims to determine the probability of flooding and to judge its acceptability in terms of the consequences. The modern probabilistic approach aims to give protection to areas with high risks. (Vrijling, 2000). The dike designs in this research are made according to a semi-probabilistic design method. This is the most recent method for the designing and testing of water retaining structures. It is not possible yet to make a dike design with a fully probabilistic design method. The difference between a semi-probabilistic method and a probabilistic method is that a semi-probabilistic design method works with designs values for the loads on the dike and the strength of the dike. These design values consist of a strength parameter and a safety factor. A probabilistic design approach is based on the probability that the load on the dike (S) is bigger than the strength of the dike (R) is lower than a certain requirement for the failure probability (P_T). This can also be displayed as: $P(R < S) < P_t$. (Ministry of Infrastructure and the Environment, 2015).

1.4 Research aim

The research aim of the bachelor thesis is to design a dike for KEMA Laboratories near the Lower Rhine by using a semi-probabilistic design method. A semi-probabilistic method is the most recent method to test and design dikes. The new method is presented in the "Deltaprogramma 2015". The government aims to complete the new norms on 1-1-2017 so that from that moment designs and tests will be made according to the new standards for flooding. For the bachelor thesis the main research question that will be answered is: **What dike design scores best on the given requirements and boundary conditions using a semi-probabilistic design method?**

To answer the main research question the following sub questions will be answered:

- What are the requirements and boundary conditions at the location?
- What dike designs are feasible at the location?
- What are the costs of the designs?
- What design scores best on the given the boundary conditions, requirements and wishes?

1.5 Limits and boundaries of the research

For the research the following limits and boundaries are established:

- Since the location of KEMA Laboratories is not located on a dike ring, it is assumed that it is located on dike ring 47-1. The maximum accepted chance of failure and the new norm for exceedance probability of dike ring 47-1 will be used as an input for the design. So the maximum fail probability will not be computed for the specific area, but will be taken from the data of dike ring 47-1. The location of KEMA Laboratories is close to dike ring 47-1. If the new dike at the location breaches this will not have impact on dike ring 47-1.

- The designs will be made on the basis of the boundary conditions for the requirements of height, stability and piping. The requirements for the failure mechanisms micro stability and stability of the foreland will not be taken into account for the designs, since these failure mechanisms are determined completely deterministic (Ministry of Infrastructure and the Environment, 2015).

- The dike design will be based on a two dike sections, which means that the required properties for two sections will be calculated. These two dike sections will be calculated and will be seen as normative for the dike.

- The costs of the designs will be determined with the methods and programs that are used by the department for cost calculation of Witteveen+Bos. There will be no adaptations in this cost calculation.

- The effect of the dike on local flow and environmental conditions after the dike is realized will not be taken into account for the research. The focus of the research is on the design of the dike.

1.6 Research method and approach

Research method

The dike is designed using a semi-probabilistic design method. The research is done according to method that is described in “Handreiking ontwerpen met Overstromingskansen” (Ministry of Infrastructure and the Environment, 2015). This report gives an addition to the all existing guidelines for the design and calculations for dikes. Besides this manual the following technical reports are used for the designs of the dike:

- Achtergrond Rapport Ontwerpinstrumentarium 2014 (Ministry of Infrastructure and the Environment, 2015)
- Technisch Rapport Grondmechanisch Schematiseren bij Dijken (expertisenetwerk waterveiligheid, 2012)
- Technisch Rapport Klei voor Dijken (Technische Adviescommissie voor de Waterkeringen, 1996)
- Technisch Rapport Ontwerpbelastingen voor het Rivierengebied (Ministry of Transport, Public Works and Water Management, 2007)
- Technisch Rapport Waterkerende Grondconstructies (Technische Adviescommissie voor de Waterkering, 2001)
- Technisch Rapport Waterspanningen bij Dijken (Technische Adviescommissie voor de Waterkeringen, 2004)
- Technisch Rapport Zandmeevoerende Wellen (Technische Adviescommissie voor de Waterkeringen, 1999)
- Werkwijze bepaling Hydraulische randvoorwaarden (Deltares, 2015)

Approach

The research for the dike has been conducted as follows: Firstly, the current situation is researched, a problem definition is defined and a literature research has been conducted. Secondly, the boundary conditions are determined. There are five categories for the boundary conditions: requirements and wishes of KEMA Laboratories, hydraulic boundary conditions, geometric boundary conditions, geotechnical boundary conditions and geo-hydrological boundary conditions. Thirdly, the design calculations are made for height, piping and macro stability. If all the design calculations are made, then the properties for the dike are determined. Fourthly, with the properties of the dike the dike design can be made. In this phase also the costs of the designs options are calculated. Fifthly, a multi-criteria analysis is used to choose the optimal dike design for KEMA Laboratories. At last, the discussion, conclusion and recommendation are formulated. The approach is also shown schematically in Figure 3.

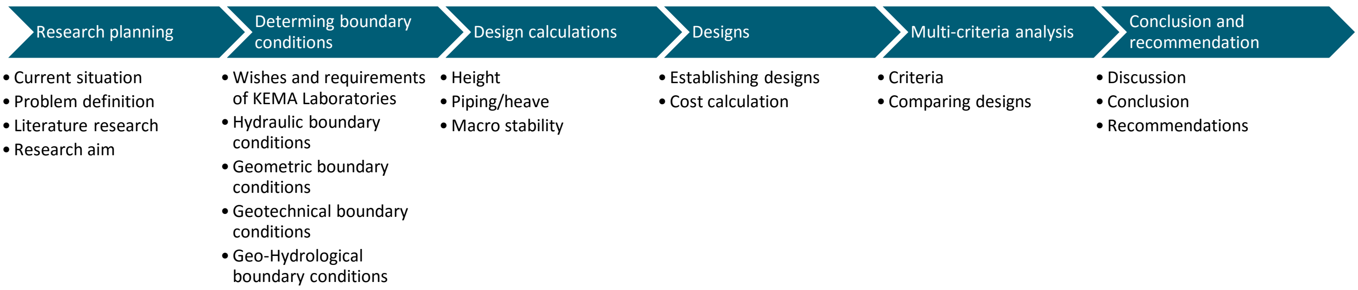


Figure 3: Research approach

Used models

For the research and the design of the dike various models are used.

- Model for simulation the water levels and the hydraulic load at KEMA Laboratories

The water levels and the hydraulic load are simulated in the program “Hydra Zoet”. “Hydra Zoet” is based on a probabilistic model that compares different scenarios for wind and water and calculates the scenario which has the highest probability of occurrence. This model is used to determine the water levels and wave properties by different return periods. The data that is produced by this model is later used for the calculations of height, piping and macro stability.

- Model for calculating the required height

The required height of the dike is determined in PCOverslag. The model determines the minimum height of a dike for a certain allowed overtopping flow. The calculations of PCOverslag are based on empirical formulas for overtopping discharge. The empirical formulas are based on lab and field research that determine the wave overtopping given the slope of the dike, the wave direction, the wave height and roughness parameters. The model is based on the technical report “Technisch Rapport Golfoploop en Golfoverslag bij Dijken”.

- Model for piping

The calculations for piping are done with the formulas for piping of Sellmeijer. De formulas of Sellmeijer are described in the technical report “Technisch Rapport Zandmeevoerende Wellen”. The calculations are based on empirical formulas. The used formulas of Sellmeijer can be found in Annex C2.

- Model for macro stability

The model of Bishop is used for the calculations of macro stability. In the program D-Geostability the different dikes are modelled. D-Geostability is a program in which the soil structures and geometry of the dike can be drawn. After adding the characteristics of the soil, the program can calculate the safety factor of the macro stability of the dike. Macro stability in this research is calculated based on the equations of the model of Bishop.

- Model for phreatic water levels

Phreatic water levels in the dike are determined for the calculations of macro stability. In absence of a local geo-hydrological model for phreatic lines, the calculation methods described in the technical report “Technisch Rapport Waterspanningen bij Dijken” (Technische Adviescommissie voor de Waterkeringen, 2004) are used to determine the water levels in the dike. The phreatic lines and the used model are further explained in paragraph 2.5 Geo-hydrological boundary conditions.

- Model for cost calculation

The cost of the different dike designs are established with the department for cost calculation of Witteveen+Bos. The cost calculation is based on the standard systematic for cost calculations of the CROW. Only the construction costs are taken into account for the cost calculation. In the cost calculation secondary costs are expressed into percentages of the construction costs. These percentages are determined by Witteveen+Bos based on their experience with cost calculations.

1.7 Reading guide

The structure of the report is as follows. In the main report all conclusions and a summary of the results can be found. More information about the data or the calculations can be found in the corresponding Annex. In every chapter there will be a reference to the Annex with additional information.

In Chapter 2 all boundary conditions can be found that are established for the research. There are five types of boundary conditions taken into account: requirements and demands of KEMA Laboratories, hydraulic boundary conditions, geometric boundary conditions, geotechnical boundary conditions and geo-hydrological boundary conditions.

In Chapter 3 an overview of the calculations for height, piping and macro stability can be found. In the chapter there will be references to the corresponding annexes, in which the calculations are more described and explained.

In Chapter 4 a description of the feasible designs can be found. The dike designs are defined and a cost calculation is done to determine the construction costs of the dike designs. In Chapter 5 a multi-criteria analysis is conducted on the feasible designs. In this chapter the criteria, an analysis of the dike designs and the multi-criteria analysis can be found.

In Chapter 6, the conclusion, discussion and recommendations for further research are formulated.

2. Requirements and boundary conditions

The designs for the dikes will be made based on the limits and boundaries of the locations. Before the designs are made, the requirements and boundary conditions are established. The requirements and boundary conditions are divided into five categories: the wishes and requirements of KEMA Laboratories, the hydraulic boundary conditions, the geometric boundary conditions, geotechnical boundary conditions and the geo-hydrological boundary conditions.

2.1 Requirements and demands of KEMA Laboratories

In order to make the designs for the dike, the requirements and wishes of KEMA Laboratories have to be established. The following requirements and wishes of KEMA Laboratories have been taken into account for the designs:

- The dike should have a crest width of 4 meters, in order to accommodate maintenance vehicles like mowers.
- The dike has to be a green dike, which means that there will be a grass revetment on the dike for erosion protection and spatial value.
- KEMA Laboratories demands two options for the dike location. They demand an option on the foreland on the dike and an option on the terrain close to the laboratories. The underlying assumption is that the option on the foreland is more expensive, but has less impact on the terrain of KEMA Laboratories and the current infrastructure.
- Maintenance vehicles, like mowers, have to be able to ride on the dike. This should be taken into account in the temporary load on the dike and in the calculations of macro stability of the inner and outer slope of the dike.
- KEMA Laboratories prefers not to lose too much of the hardened surface of the area around the laboratories and demands that all buildings will be retained.

2.2 Hydraulic boundary conditions

The hydraulic boundary conditions are determined with the “Werkwijze bepaling hydraulische ontwerprandvoorwaarden” (Deltares, 2015). The design water levels and the wave conditions have been determined in order to form the hydraulic boundary conditions. The design water levels and the wave conditions are determined in ‘Hydra Zoet’. Hydra Zoet is a probabilistic model that combines wind and discharge scenarios. It is developed by Rijkwaterstaat and it can be used for testing and determining hydraulic boundary conditions of water-retaining structures near fresh water with a semi-probabilistic method. All calculations for the hydraulic boundary conditions can be found in Annex A.

Design water levels

The design water levels are determined with “Werkwijze bepalen hydraulische ontwerprandvoorwaarden” (Deltares, 2015) corresponding to “Handreiking ontwerpen met Overstromingskansen” (Ministry of Infrastructure and the Environment, 2015). In Hydra Zoet the water levels are simulated for six return frequencies: 1/1.000, 1/2.000, 1/4.000, 1/10.000 and 1/20.000 years for different climate scenarios. In order to determine the design water level the scenario warm+ is used, because this scenario gives the highest water levels. The choice is made to use the most conservative water levels for the calculation of the height of the dike. The water levels are used to determine the crest height of the dike. Usually for the design of dikes, the water levels of scenario average+ are used as the design water levels (Ministry of Transport, Public Works and Water Management, 2007). In this case the choice is made to use the most extreme scenario to make a robust design. Future expansions of the dike (for example in case of a higher norm for the dike) are hard to realize due to the limited space at the location and the high cost of such an expansion. Since there is no data on the exact location of KEMA Laboratories, the data from a location that is located

1,8 km upstream KEMA Laboratories is used for the simulation of the water levels. The simulated water levels are corrected with an uncertainty addition of +0,30m and a correction for the slope of the river with -0,18 m. The simulated water levels, the corrected water levels and their return periods are shown in Table 1.

Table 1: Corrected water levels at KEMA Laboratories

Return period (years)	Simulated water levels (m +NAP)	Corrected water level (m +NAP)
1.000	13,76	13,88
2.000	13,86	13,98
4.000	13,96	14,08
10.000	14,08	14,20
20.000	14,18	14,30

In this research it is assumed that KEMA Laboratories is located on dike ring 47-1. The norm for the allowed failure probability of height for this dike ring is 1/4.170 years for this dike ring (Ministry of Infrastructure and the Environment, 2015). So the simulated water level of 14,08m that occurs with a return period of 4.000 years is used as the design water level for the calculation of the required height.

Wave conditions

The wave conditions are determined with "Hydra Zoet". Since the location of KEMA Laboratories is near water at both sides, wave conditions are determined for both locations. Two locations are specified for the determination of the hydraulic boundary conditions, which are location west and location south. This is shown in Figure 4. Hydra Zoet is used to calculate the wave heights and the hydraulic loads.

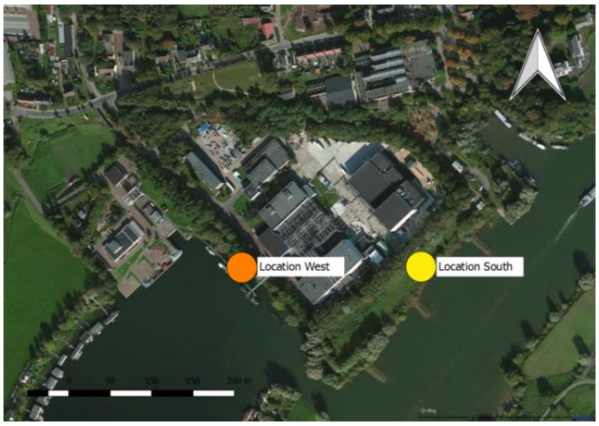


Figure 4: Location west and south at KEMA Laboratories

The wave run-up depends on the water level, the dike orientation, wave height and slope of the dike. The normative water level and the wave height are influenced by the other parameters, due to the probabilistic nature of determination of the hydraulic boundary conditions. The outer slope is calculated for a slope with a ratio of 1:3. The return period for the wave conditions are 4.000 years. The simulated significant wave height (Hs) and spectral wave period (Tm-1) corresponding to this slope are shown in Table 2. This data is used later on as input in PCOverslag to calculate the required crest height given the allowed overtopping flow.

Table 2: Significant wave height (Hs) and spectral wave period (Tm-1) for locations south and west

Location	Hs (m)	Tm-1 (s)
South	0,53	2,5
West	0,66	2,8

Ground level at KEMA Laboratories

The ground levels at KEMA Laboratories are established with data from the height data of AHN (“Actueel Hoogte Bestand”) and Bingmaps in QGis. The heights at the location are shown in Figure 5. The ground levels are used in the calculations for piping and macro stability.

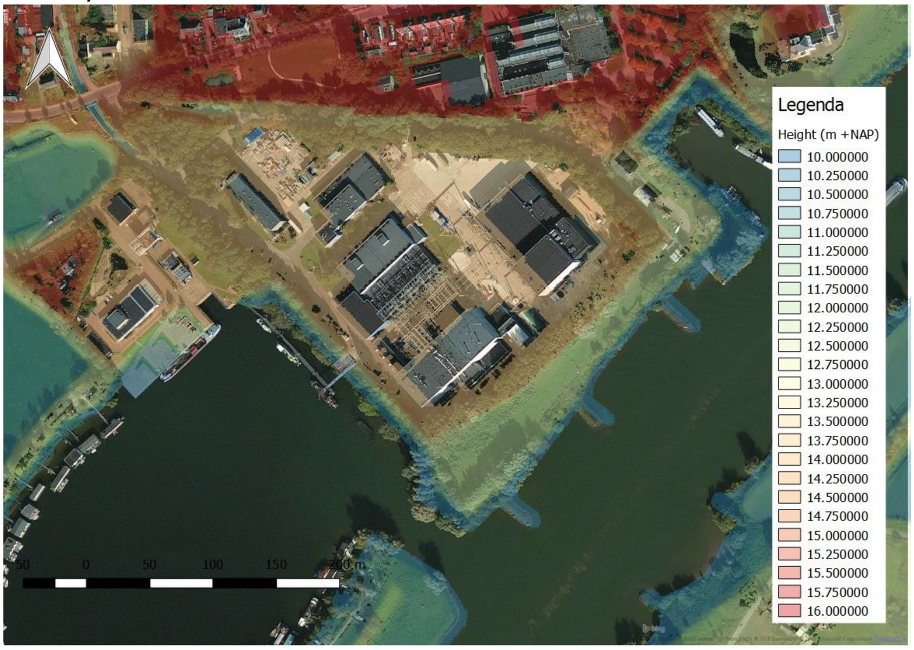


Figure 5: Height at locations in m +NAP (Actueel Hoogtebestand Nederland, 2014)

Allowed overtopping flow

The allowed overtopping flow for the designs is 0,1 L/s/m. Since an overtopping flow at this location is not desired, the lowest possible overtopping flow is used for the calculations (Ministry of Infrastructure and the Environment, 2015). With this overtopping discharge there are no restrictions for the revetment on the inner slope of the dike. The allowed overtopping flow is used in the calculations for the required height.

2.3 Geometric boundary conditions

Current geometry

As is shown in Figure 5 there is a height difference between the ground level at the terrain of KEMA Laboratories and the foreland. Two sections are made from the foreland on location west and location south. The sections are shown in Figure 6 and Figure 7. More information about the establishing of the current geometry can be found in Annex B. These sections are used to estimate the current geometry of the area around KEMA Laboratories. The slope of the current geometry is estimated on a ratio of 1:3. This slope is used for the calculations of the dike designs on the terrain of KEMA Laboratories. For the calculations it is assumed that the ground level at the terrain is 13,9 m +NAP, the ground level at the foreland 12,1 m +NAP and the ground level at the outer base of the dike is 10,1 m +NAP. The current geometry is used as an input for the calculations of macro stability and the cost calculations.

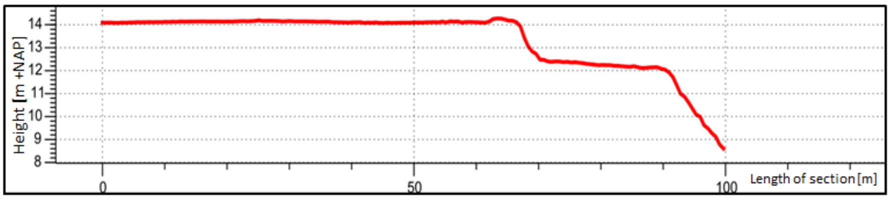


Figure 6: Current geometry of the foreland on location south (Actueel Hoogtebestand Nederland, 2014)

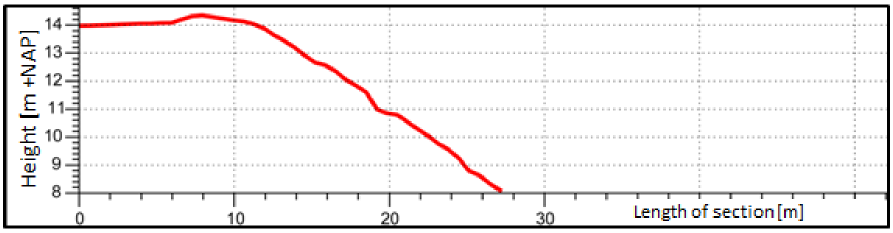


Figure 7: Current geometry of foreland on location west (Actueel Hoogtebestand Nederland, 2014)

Crest width

A requirement of KEMA Laboratories is that the dike has a crest width of at least 4 m, so that maintenance vehicles are able to ride on the dike.

Location of the dike

The dike options will be designed for two locations for the dike. The dike will either be on the foreland of KEMA Laboratories or on the terrain of KEMA Laboratories. The two locations are shown in Figure 8 and Figure 9.

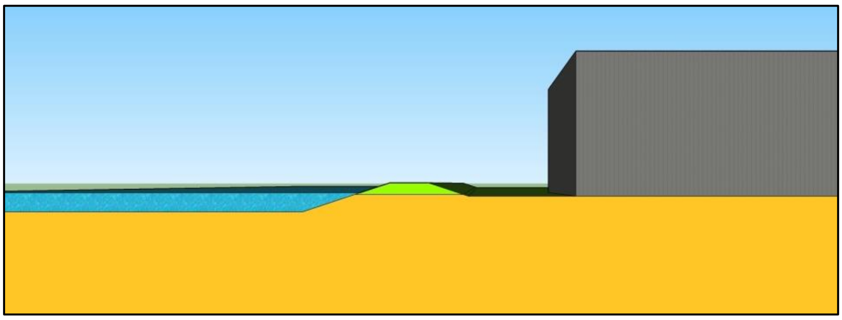


Figure 8: Dike design on the terrain of KEMA Laboratories

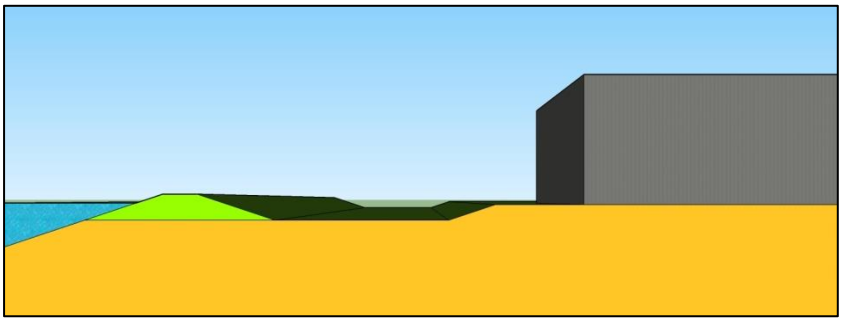


Figure 9: Dike design on foreland of KEMA Laboratories

2.4 Geotechnical boundary conditions

Soil structure

At the location of KEMA Laboratories eight borings have been performed. The locations of the eight borings are shown in Figure 10. There are no borings performed at the exact location of the dikes so an estimation of the soil structure is made. The data from the eight borings are compared, but it was not possible to deduce a general soil structure of the area around KEMA Laboratories. So for the dike designs the data of boring B40A0374 and B40A0179 are used, since these borings are closest to the location of the new dike.

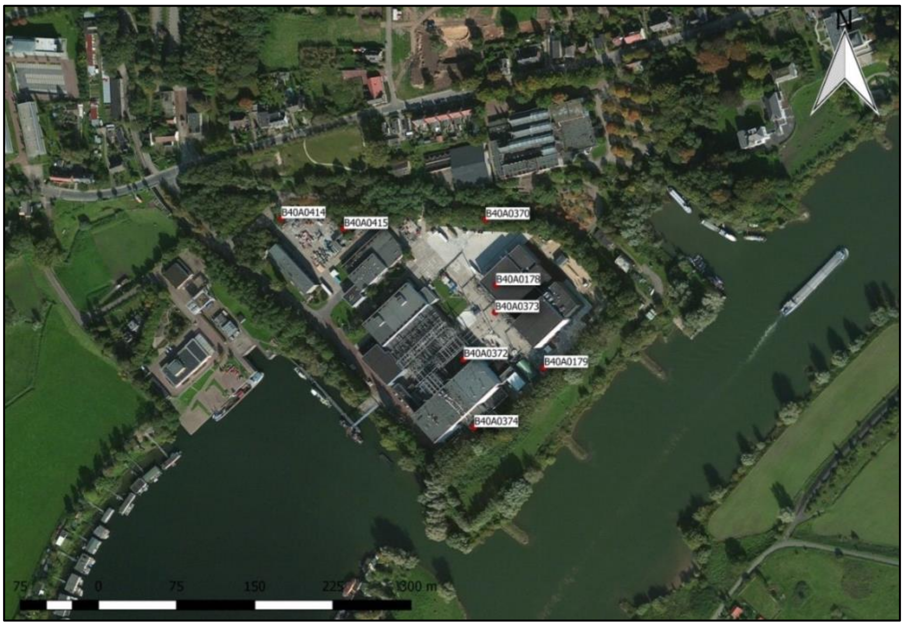


Figure 10: Location soil borings at the location of KEMA Laboratories

Different borings are used for the calculations of piping and macro stability. The data from boring B40A0179 (shown in Table 3) is used for the calculations of macro stability and the data from boring B40A0374 (shown in Table 4) is used for the calculations of uplifting and piping. This is the most conservative assumption, since boring B40A0179 has a thicker layer of clay. This means that this soil is more sensitive for macro stability because clay has lower strength characteristics than sand. Since there is no sample from the top layer of the ground it is assumed for the calculations that this is clay, since this is the soil that has the lowest strength characteristics.

Table 3: Soil structure at location B40A0179

From [m +NAP]	To [m +NAP]	Soil type
12,00	11,00	No sample
11,00	8,00	Clay, sandy
8,00	2,00	Sand, gravelly
2,00	-1,00	Sand
-1,00	-3,00	Sand, gravelly

Boring B40A0374 is used for the calculations of piping. This soil boring is more sensitive for the failure mechanism piping, because the covering layer is thinner than from boring B40A0179. The soil boring is more sensitive for uplifting since the covering layer is thinner, so it is more like to lift due to the water pressure and if uplifting is possible then piping can occur.

Table 4: Soil structure at location B40A0374

From [m +NAP]	To [m +NAP]	Soil type
13,20	12,90	Sand
12,90	12,44	Sand, gravelly
12,44	10,94	Clay
10,94	10,65	Sand
10,65	10,10	Sand, clayey
10,10	9,60	Sand, gravelly
9,60	7,94	Gravel
7,94	3,48	Sand, gravelly
3,48	3,20	Sand
3,20	3,00	Gravel

The two used borings only have data up to 3m +NAP. Since the failure mechanism piping occurs in the aquifer under de covering clay layer it is necessary to determine the thickness of the aquifer. There is one deeper boring performed at the location of KEMA Laboratories (up to a depth of -90 m +NAP). This data is used in combination with a section of the soil structure of the area to estimate the thickness of the aquifer on 21m. The data from the borings and explanations can be found in Annex C1 and Annex C2.

Material of the dike

There are two options for the materials of the dike design. The first option is a sand dike with a top layer of clay. The second option is dike completely made out of clay. The material of the dike has influence on the phreatic water levels in the dike and depends on the maximum allowed overtopping flow.

Revetment

A requirement of KEMA Laboratories is that the dike has to be a green dike. This means that the dike has a revetment of grass. With the chosen maximum allowed overtopping flow of 0,1 L/s/m there are no requirements for the revetment of the dike.

Ground characteristics

The ground characteristics are determined with the data Table 2b from NEN-1997-1 +C1 for the characteristic values of the soil. This table can also be found in Annex C3. The ground characteristics are used in the calculations for piping. The characteristics are shown in Table 5 and Table 6.

Table 5: Characteristics of the clay and sand

Characteristic	Symbol	Clay	Sand
Volumetric weight saturated	γ_{sat}	17 kN/m^3	20 kN/m^3
Volumetric weight dry	γ_{dry}	17 kN/m^3	18 kN/m^3
Cohesion	c	5 kPa	0 kPa
Angle of internal friction	φ	17,5°	32,5°

Table 6: Additional characteristics of sand

Characteristic	Symbol	Value
70-percentile value of the grain distribution	d70	2,10*10^{-4}
Angle of internal friction	θ	37°
Permeability	k	2,85*10^{-4} m/s
Intrinsic permeability	κ	3,85*10^{-11} m^2

2.5 Geo-hydrological boundary conditions

Phreatic water levels

The phreatic lines in the dikes are calculated for the calculations of macro stability of the inner and outer slope. In every design there are two phreatic lines. The first line is the line that is calculated with the technical report “Technisch Rapport Waterspanningen bij dijken” (Technische Adviescommissie voor de Waterkeringen, 2004). The second phreatic line is the water level at the normative high water level.

Phreatic water levels for macro stability of the inner slope

Two phreatic lines are schematized for the calculations of macro stability of the inner slope. The first phreatic line is calculated with the formulas from “Technisch Rapport Waterspanningen bij dijken”. The phreatic line in a clay dike is different than a phreatic line in a sand dike with clay cover. An example from the phreatic lines in sand and clay dikes is shown in Figure 11 and Figure 12. The second phreatic line is the line at the level at normative high water. The maximum accepted chance of failure mechanism macro instability is 1/1.000 years (Ministry of Infrastructure and the Environment, 2015). The normative high water level with a return period of 1.000 years is 13,88m +NAP. This water level is used for the calculations for the macro stability of the inner slope.

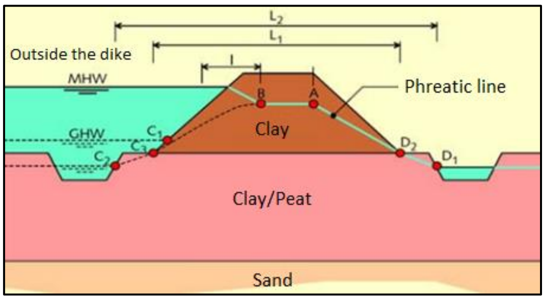


Figure 11: Phreatic line in a clay dike (Technische Adviescommissie voor de Waterkeringen, 2004)

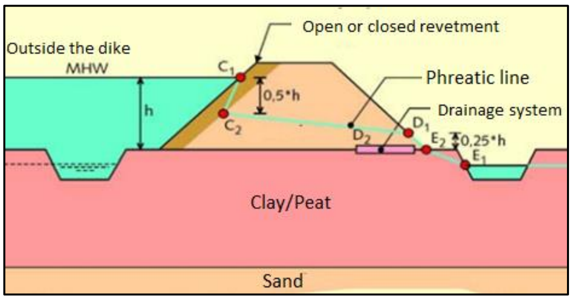


Figure 12: Phreatic line in a sand dike with clay cover (Technische Adviescommissie voor de Waterkeringen, 2004)

Phreatic water levels for macro stability of the outer slope

For the phreatic water level for the calculation of the macro stability of the outer slope the dike is fully saturated. The dike is saturated, which means that the first phreatic line inside the dike stays the same as in the calculations for the inner slope, except that the line decreases 30 cm beneath the outer slope surface to the second phreatic line. It is assumed that the top layer is not saturated, since this layer is of a lower quality and has a grass revetment. So the water cannot stay inside this layer (Technische Adviescommissie voor de Waterkeringen, 1996) . The second phreatic line is a line on the mean high water level. For the calculations the water level of 11,35 m +NAP. This is the annual high water level in the Lower Rhine at Arnhem (Rijkswaterstaat, 2016). This water level is used for the calculations for the macro stability of the outer slope.

3. Design calculations and output

In this chapter a summary of the design calculations for height, piping and macro stability can be found. The results from the calculations determine the properties of the dike designs. At the end of this chapter the required properties for the dike designs are clear and the dike designs can be made. All design calculations can be found in the Annex. In every subparagraph there will be a reference to the corresponding Annex.

3.1 Crest height

The required crest height is calculated for the west and the south location. The two dikes are calculated with a 1:3-dike profile. For the calculation of height the hydraulic load on the dike is simulated in "Hydra Zoet". The requirement for the failure mechanism height is 1/4.170 year (Ministry of Infrastructure and the Environment, 2015). So the used design water level from the simulated hydraulic load on the dike has a return period of 4.000 years. The input that is used for the calculations is shown in Table 7. The water level that occurs with a return period of 4.000 years is 14,08m +NAP. There is no data available about the normative storm duration, so the choice is made to estimate the normative storm duration on the maximum value of 20.000 s (±5,5 hours).

Table 7: Input PCOverslag for determination of required height at location south and west

Input	Symbol	Unit	Data location south	Data location west
Significant wave height	Hmo	Meters	0,53 m	0,66 m
Wave direction	β	Degrees	73°	24°
The spectral wave period	Tm-1	Seconds	2,5 s	2,8 s
Water level	SWL	Meters	14,075 m	14,075 m
Normative storm duration	Tsm	Seconds	20000 s	20000 s
Average wave period	Tm	Seconds	2,0 s	2,0 s

**Angle between dike normal and wave direction with respect to North*

With this input the required crest height is determined with PCOverslag. PCOverslag calculates the required the required height for the dike for four different overtopping flows. The allowed overtopping flow is the amount of water that is allowed to flow over the dike. In Figure 13 an explanation of overtopping flow is shown. The choice is made for the designs for a maximum overtopping flow of 0,1 L/s/m. Since an overtopping flow is not desired at the location, the lowest possible overtopping flow of 0,1 L/s/m is used for the calculations.

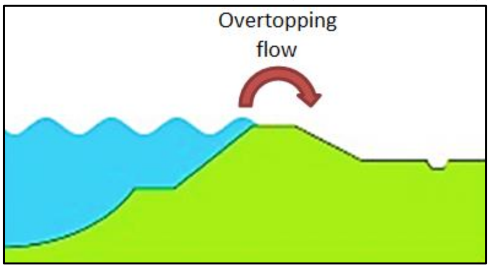


Figure 13: Overtopping flow over the dike

Required crest height

The calculated required crest heights at the locations are shown in Table 8. These heights will be used as input in the calculations for the stability calculations. There is a difference in height for the dike on location west and on location south. This is because the dikes have a different orientation on the direction of the waves. For the dike on location west the wave direction is 24°. This means that the waves come almost straight on the dike. Because of this, the wave run up is higher and that leads to a higher required dike. All calculations and extra explanations can be found in Annex D1.

Table 8: Required crest height for profile 1:3

Location	Height (m +NAP)
South	15,1
West	15,7

3.2 Piping

By the failure mechanism piping, the dike fails because water and soil particles can flow through or under the dike. The failure mechanism piping is shown in Figure 14. In order to make sure that the dike will not fail because of piping the designs have to be checked for piping. Piping can only occur if uplifting can happen at the location. By uplifting the water pressure from below is higher than the ground pressure, which allows water to push the ground away and flow under the dike. If uplifting is possible, this does not mean that the dike will fail. But the dike will need a minimum width, in order to prevent the soil particles from flowing through the dike, because this will lead to a failure of the dike. At first the dike locations where piping can occur are checked for uplifting. If uplifting can occur then the required seepage length is determined. The required seepage length determines a property for the dike designs.

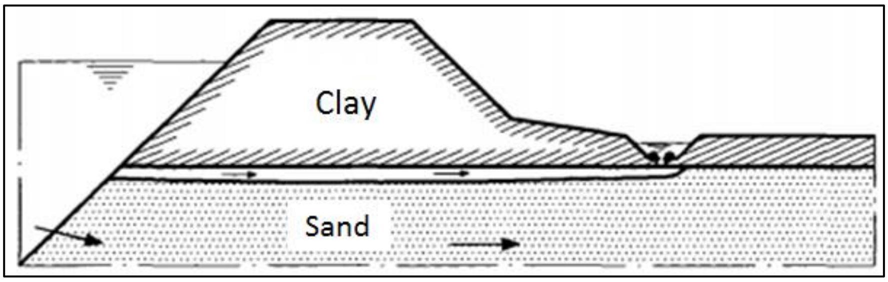


Figure 14: The failure mechanism piping (Technische Adviescommissie voor de Waterkeringen, 1999).

Soil structure of boring B40A0374 is used for the calculations of piping (shown in Table 4). This is a conservative assumption, since the soil structure of this boring has a thinner layer of clay; the ground is more sensitive for uplifting. Piping and uplifting are calculated with the formulas described in ‘Handreiking ontwerpen met overstromingskansen” (Ministry of Infrastructure and the Environment, 2015) and the formulas of Sellmeijer (Technische Adviescommissie voor de Waterkeringen, 1999). According to “Handreiking ontwerpen met overstromingskansen” the design water level for piping is the water level with an exceedance probability similar to the maximum accepted chance of failure (Ministry of Infrastructure and the Environment, 2015). The maximum accepted chance of failure mechanism piping is 1/1.000 years (Ministry of Infrastructure and the Environment, 2015). The simulated water level that occurs with a return period of 1.000 years is 13,88m +NAP. This design water level will be used for the calculations of uplifting and piping. All calculations for piping and uplifting can be found in Annex D2.

Uplifting

Uplifting is checked on two locations: for the dike on the foreland and for the dike on the terrain of KEMA Laboratories. The ground level of the foreland is 12,10m +NAP and at the terrain of KEMA Laboratories the ground level is 13,9m +NAP. The used soil structures for the calculations are shown in Figure 15 and Figure 16. These soil structures are deduced from the soil boring B40A0374. The results from this borings are linked to the ground level of the foreland and the terrain.

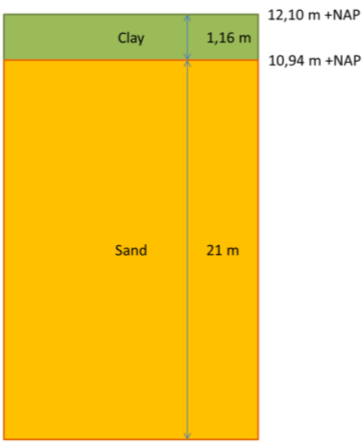


Figure 15: Soil structure for calculations for uplifting on the foreland

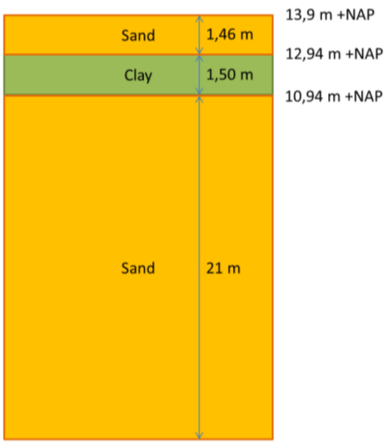


Figure 16: Soil structure for calculations for uplifting on terrain of KEMA Laboratories

Calculations uplifting

Uplifting is calculated with the formulas that are described in "Handreiking ontwerpen met overstromingskansen" (Ministry of Infrastructure and the Environment, 2015). The formula calculates the ratio between the ground pressure and the water pressure. If $\frac{ground\ pressure}{water\ pressure} \geq 1{,}0$, then uplifting cannot occur at the location. The results from the calculations for piping and uplifting are shown in Table 9. All calculations for uplifting can be found in Annex D2 .

Table 9: Results calculations uplifting

Location	Ground pressure	Water pressure	$\frac{ground\ pressure}{water\ pressure}$	Does uplifting occur?
Foreland	7,3 kN/m^2	30,5 kN/m^2	0,24	Yes
Terrain of KEMA Laboratories	22,6 kN/m^2	12,5 kN/m^2	1,81	No

So in conclusion, piping on the foreland can occur. Uplifting is possible at the foreland and this means that piping is a relevant failure mechanism. The required seepage length needs to be calculated. Piping through a deeper sand layer cannot occur at the terrain of KEMA Laboratories.

Calculations piping

Since uplifting is possible on the foreland the required seepage length is calculated. The seepage length is determined with the formulas of Sellmeijer, which are described in the technical report "Technisch Rapport Zandmeevoerende Wellen" (Technische Adviescommissie voor de Waterkeringen, 1999).

Factor of schematization

In order to determine the seepage length first the factor of schematization is determined. This factor accounts for uncertainties in the soil structure, water pressure and other input parameters. This factor is one of the safety factors that are in the formula of Sellmeijer. The factor of schematization γ_b is estimated with the method described in the technical report "Grondmechanisch schematiseren bij Dijken" (expertisenetwerk waterveiligheid, 2012). The factor of schematization is estimated based on the following scenarios:

1. The ground level on the inside of the dike is 0,3m lower
2. The layer of clay is 0,5m thinner
3. The aquifer is 35m thick instead of 21m
4. Locally the layer of clay is missing

With this method the factor of schematization is estimated on 1,13. The factor is schematization is calculated for the dike on the foreland on location south. This is the only location where piping can occur. Piping on the west location is not possible since the design is partly located on the terrain of KEMA Laboratories and there is no gravity flow. All calculations for the scenarios and the determination of the factor of schematization can be found in Annex D2.

Strength factor

The other safety factor is the strength factor γ_{mp}. This factor depends on the reliability requirement which is given in "Handreiking ontwerpen met overstromingskansen". The γ_{mp} is 1,20 for dike ring 47-1 (Ministry of Infrastructure and the Environment, 2015).

Seepage length

The calculated seepage length is calculated with the formula of Sellmeijer, which is described in the technical report "Technisch Rapport Zandmeevoerende Wellen" (Technische Adviescommissie voor de Waterkeringen, 1999). The required seepage length is determined for the dike design on the foreland of KEMA Laboratories, since this is the only location where piping can occur. The calculated seepage length with the strength factor γ_{mp} of 1,20 and a schematization factor γ_b of 1,13 gives a seepage length of 31,0 m. The distance between the entrance point of the water and the outlet point has to be more than 31 meter apart to prevent piping.

3.3 Macro stability

Due the failure mechanism of the macro stability the dike and the ground under the dike slides away, which causes the dike to fail. The macro instability of the inner slope is shown in Figure 17. For the calculations of macro stability of the designs the stability of the inner and the outer slope is determined. First the safety factors for the inner and outer slope are calculated. Thereafter different dike designs are modelled in D-Geostability and the safety factor is calculated. If the safety factor of the model is higher than the calculated safety factor, then the design is considered safe for the failure mechanism macro stability. If the dike design is considered safe, then the design can be used as a possible design for the final design.

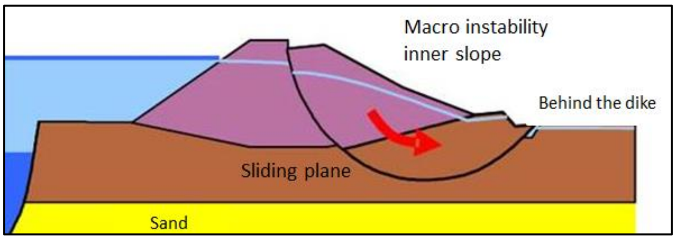


Figure 17: Macro instability of the inner slope

The dike designs are modelled based on the soil structure of boring B40A0179, shown in Table 3. Since there is no sample of the top layer of the soil structure the most conservative assumption is made. It is assumed that the top layer is clay, since this type of soil has the weakest strength characteristics. The used soil structure is shown in Figure 18.

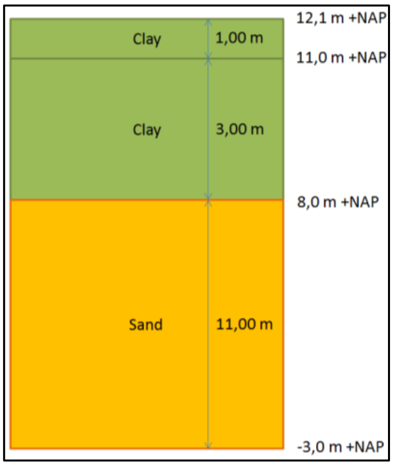


Figure 18: Soil structure used for calculations of macro stability

One of the requirements of KEMA Laboratories is that maintenance vehicles should be able to ride on the dike. So a load of 5 kN/m^2 is added to the designs. The minimum slope where maintenance vehicles are able to ride on the dike is 1:3. According to the technical report "Technisch Rapport Waterkerende Grondconstructies" the load of traffic on a dike is 13,3 kN/m^2. However this load is estimated for trucks loaded with sandbags, so the traffic load of maintenance vehicles is in consultation with Witteveen+Bos estimated on 5 kN/m^2.

For the soil characteristics the characteristic values from NEN 1997 are used. On this characteristic values a material factor is used. The used material factor and design values are shown in Table 10. The material factor are from the addendum by the technical report "Technisch Rapport Waterkerende Grondconstructies" (Technische Adviescommissie voor de Waterkering, 2007). The table with the material factors can be found in Annex C3. The design values are established by dividing the characteristic value by the material factor. Note that the design value for the angle of internal friction is established by dividing the tangent of the angle of the internal friction by the material factor.

Table 10: Design values of the soil for the calculations for macro stability

Material	Characteristic	Characteristic value from NEN 1997	Material factor	Design value
Sand	Cohesion	0	N.A.	0
	Angle of internal friction	32,5°	1,20	28°
Clay	Cohesion	5 kPa	1,25	4 kPa
	Angle of internal friction	17,5°	1,20	15°

The macro stability of the dikes will be calculated for two locations: west and south and in two types of material: sand and clay. On the location of KEMA Laboratories the dike can be placed at the foreland or at the terrain of KEMA Laboratories. The option on the terrain is not possible at location west, since there is too little space at the terrain of KEMA Laboratories for the dike. The variant on the foreland at the terrain of location west will partly be on the terrain of KEMA Laboratories, due to the fact that there is too little space on the foreland. There will also be a variant of the west dike on the foreland. The new dike will be placed at the current geometry of the area around KEMA Laboratories. The locations and current geometry is shown in Figure 19, Figure 20, Figure 21 and Figure 22.

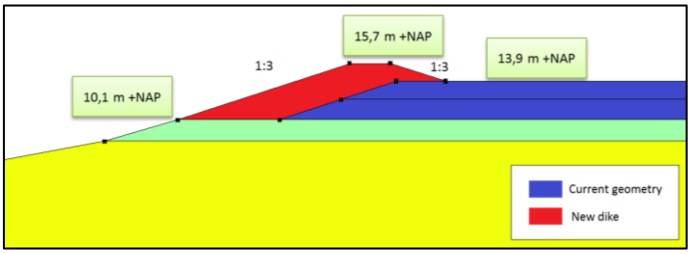


Figure 19: Dike partly on terrain of KEMA Laboratories at location west

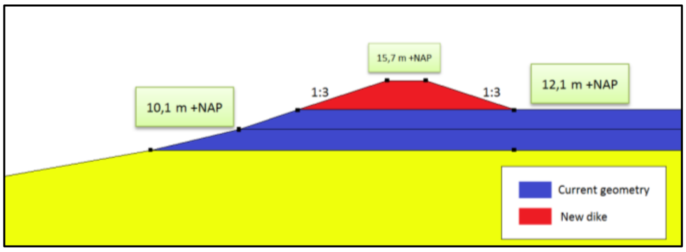


Figure 20: Dike on the foreland on location west

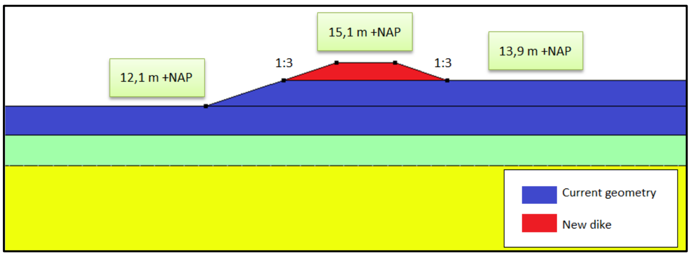


Figure 21: Dike on the terrain of KEMA Laboratories at location south

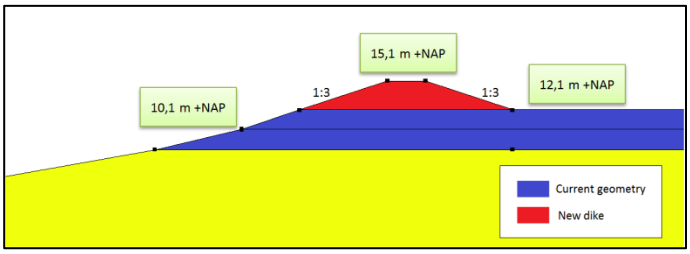


Figure 22: Dike on the foreland at location south

Safety factor macro stability of the inner slope

For the calculations first the macro stability of the inner slope is calculated. For the calculations the safety factor for the inner slope is determined with the formula of the "complement part A of the technical report "Technisch Rapport Waterkerende Grondconstructies" (Technische Adviescommissie voor de Waterkering, 2007). The calculated safety factor the inner slope is 1,17. All dike designs and the corresponding phreatic lines are modelled in D-Geostability and the dike designs have to satisfy the safety factor. The results of the dike designs in D-Geostability are shown in Table 11. The calculation of the safety factor and the elaborate results can be found in Annex D3.

Safety factor macro stability of the inner slope

After that the macro stability of the inner slope is determined, the macro stability of the outer slope is calculated. First the safety factor for the macro stability of the outer slope is determined. The safety factor of the outer slope can be determined with the same method how the safety factor of the inner slope is determined. So the same formula will be used for the determination of the safety factor of piping. Failure of the dike because of the macro stability of the outer slope only happens when the outer water level drops. This means that the fail probability on the section level can be divided by the probability of a flood due to the loss of macro stability of the outer slope. In "Handreiking ontwerpen met overstromingskansen" it is advised to use the probability of 0,1. The safety factor for macro stability of the outer slope is determined on 1,06 in consultation with the engineers of Witteveen+Bos.

Results

The results for the calculations of the macro stability of the inner and outer slope are shown in Table 11.

Table 11: Results D-Geostability of macro stability of the inner and outer slope

Nr	Location	Place	Material	Satisfies safety factor inner slope?	Satisfies safety factor outer slope?
1	West	Partly on terrain	Clay	Yes	No
2	West	Partly on terrain	Sand	Yes	No
3	West	Foreland	Clay	No	No
4	West	Foreland	Sand	Yes	No
5	South	Foreland	Clay	Yes	No
6	South	Foreland	Sand	Yes	No
7	South	Terrain	Clay	Yes	Yes
8	South	Terrain	Sand	Yes	Yes

Design optimization

The design on location west on the foreland made with clay does not satisfy the safety factor for the inner slope. For the calculations of the safety factor of the outer slope the majority of the design does not satisfy the calculated safety factor. The safety factors of the designs that are calculated in D-Geostability, are all calculated with the soil characteristics of clean clay, which has an angle of internal friction of 17,5° (characteristic value). If the used soil for the dike and the ground satisfies a value for the angle of internal friction of 22,5° (characteristic value) and so a design value of 19°. It has to be researched if the used clay for the dike designs satisfies this angle of internal friction. Alternative solutions to solve the macro instability are a lower slope or an outer berm; however these solutions require more space and soil and this is more expensive solution. The results of the calculations with a design value of 19° for the angle of internal friction for clay are shown in Table 12.

Table 12: Results D-Geostability of macro stability with stronger clay

Nr	Location	Place	Material	Satisfies safety factor inner slope?	Satisfies safety factor outer slope?
1	West	Partly on terrain	Clay	Yes	Yes
2	West	Partly on terrain	Sand	Yes	Yes
3	West	Foreland	Clay	Yes	Yes
4	West	Foreland	Sand	Yes	Yes
5	South	Foreland	Clay	Yes	Yes
6	South	Foreland	Sand	Yes	Yes
7	South	Terrain	Clay	Yes	Yes
8	South	Terrain	Sand	Yes	Yes

If the used clay for the dike designs satisfies the characteristic value of the angle of internal friction of 22,5°, then all designs satisfy the calculated safety factors and the designs can be considered safe for the failure mechanism macro stability. It has to be checked if clay that will be used for the dike satisfies this characteristic, otherwise the design does not satisfy the safety factor. All the calculations, results and calculated sliding planes can be found in Annex D3.

4. Dike designs

In this chapter all feasible dike designs that can be placed at the location of KEMA Laboratories are described. All of the dike designs in this chapter satisfy on the failure mechanisms height, piping and macro instability. In the first part of this chapter there is described how the dike options are established and in the second part the costs of the dike designs are calculated.

4.1 Dike options

With the output of the height, piping and stability calculations, there are eight dikes feasible at the location. All the feasible dikes are shown in Table 13.

Table 13: Feasible dikes at the location of KEMA Laboratories

Nr.	Location	Place	Material
1	West	Partly on terrain of KEMA Laboratories	Clay
2	West	Partly on terrain of KEMA Laboratories	Sand
3	West	Foreland	Clay
4	West	Foreland	Sand
5	South	Foreland	Clay
6	South	Foreland	Sand
7	South	Terrain of KEMA Laboratories	Clay
8	South	Terrain of KEMA Laboratories	Sand

The dikes and their possible locations are shown in Figure 23. The dikes and their locations can lead to three different options for a complete dike. There are three possible options for the designs shown in Figure 24. The first option is the option for a dike that is located all around the foreland of KEMA Laboratories. The second option is around the foreland on the south side, but leaves a small part of the foreland outside the dikes. For the third option the dikes are all located on the terrain of KEMA Laboratories. The dikes can be made out of clay or sand, so in total there are six dike designs possible.

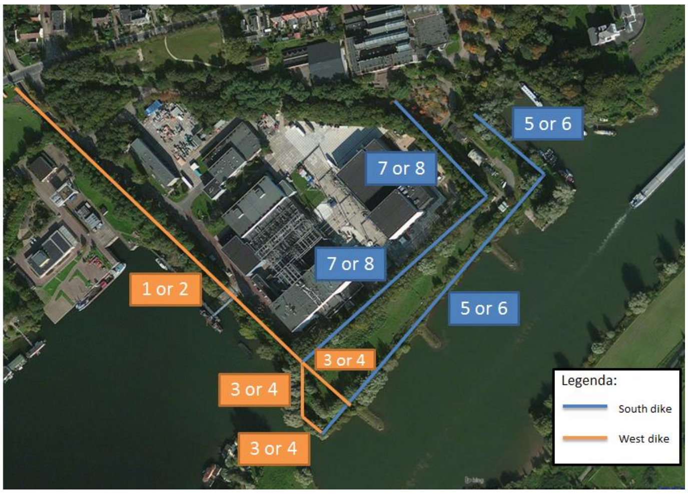


Figure 23: Individual dikes and their locations

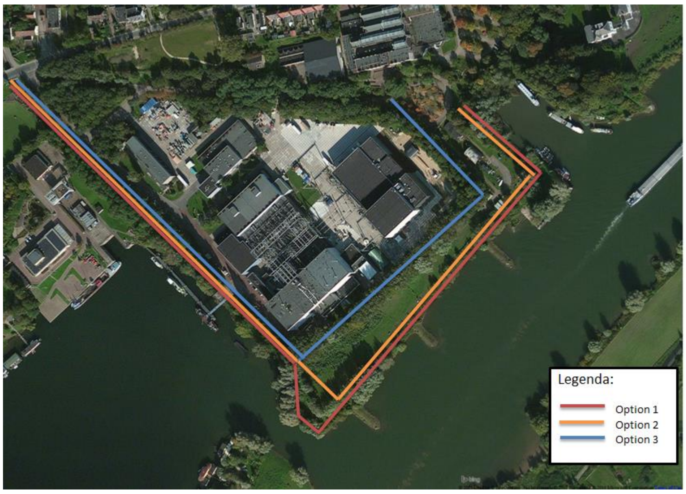


Figure 24: Possible options for dike location

The six dike designs that can be realized at the location are:

- Design 1: Clay dike all around the foreland

The first design option is a clay dike which is located all around the foreland as is shown as Option 1 in Figure 24. The west dike is partly on the terrain of KEMA Laboratories and has a height of 15,7m +NAP, the west dike is also located on the foreland of KEMA Laboratories this has the same height as the dike which is located partly on the terrain of KEMA Laboratories. The south dike is completely located on the foreland and has a height of 15,1m +NAP.

- Design 2: Sand dike all around the foreland made of sand

The second design option is the same as the first design option, but the dike is made out of sand instead of clay. This means that de core of the dike is made out of sand and that de dike has a top layer made out of clay (varying between a thickness of 1,1m and 2m). On the inside the dike has a top layer of clay with a thickness of 0,5m thickness which makes it possible to grow a grass revetment on the dike. The height of the west dike is located partly on the terrain of KEMA Laboratories and has a height of 15,7m +NAP. The south dike is 15,1m +NAP and is located on the foreland of KEMA Laboratories.

- Design 3: Clay dike on foreland with room outside the dikes

The third design option is a clay dike which is located on the foreland of KEMA Laboratories and is shown as Option 2 in Figure 24. As is shown a small part of the foreland is left out of the dike. This gives the possibility to install a pump system at this location. This design is also more cost effective, because a smaller dike is needed. The west dike is located partly on the terrain of KEMA Laboratories and has a height of 15,7m +NAP. The south dike is 15,1m +NAP and is located on the foreland of KEMA Laboratories.

- Design 4: Sand dike on foreland with room outside the dikes

The fourth design option is the same as the third design option, but the dike is made out of sand instead of clay. The dike has a sand core and a top layer of clay on the outside varying between 1,1m and 2m. On the inside the dike has a top layer of clay with a thickness of 0,5m thickness which makes it possible to grow a grass revetment on the dike. The west dike is located partly on the terrain of KEMA Laboratories and has a height of 15,7m +NAP. The south dike is 15,1m +NAP and is located on the foreland of KEMA Laboratories.

- Design 5: Clay dike on terrain of KEMA Laboratories

The fifth design option is a clay dike which is almost completely located on the terrain of KEMA Laboratories. The location of the design is shown as Option 3 in Figure 24. This dike designs requires the least amount of soil, because the terrain of KEMA Laboratories already has a ground level of 13,9m +NAP. The location of this dike design is shown in Figure 24 as option 3. The west dike is located partly on the terrain of KEMA Laboratories and has a height of 15,7m +NAP. The south dike is 15,1m +NAP and is located on the terrain of KEMA Laboratories.

- Design 6: Sand dike on terrain of KEMA Laboratories

The sixth design option is the same as the fifth design option, but the dike is made out of sand instead of clay. The dike has a sand core and a top layer of clay on the outside varying between 1,1m and 2m. On the inside the dike has a top layer of clay with a thickness of 0,5m thickness which makes it possible to grow a grass revetment on the dike. The west dike is located partly on the terrain of KEMA Laboratories and has a height of 15,7m +NAP. The south dike is 15,1m +NAP and is fully located on the terrain of KEMA Laboratories.

4.2 Cost calculation

The cost of the dike designs are calculated with the department cost evaluation of Witteveen+Bos. Not all costs are included in the cost calculation. Usually a cost evaluation consists of construction costs, real estate costs, engineering costs, risk reservations and other associated costs. The choice is made to estimate only the construction costs, because in this phase of the design process the other costs are expressed in percentages of the construction cost and these are not distinctive for the designs. The full cost evaluation can be found in Annex E2. For the cost calculation the cost are calculated for the individual dikes. The cost evaluation is made with the following assumptions:

- The material for the dikes is not available on the location
- Only the construction costs are taken into account
- There is no soil improvement needed on the location
- Costs are calculated for the full dikes and not for the individual dike paths. The indirect costs have a percentage that fits by the realization of a full dike and not for the realization of individual parts.

For the cost calculation first the surface area of the materials are determined from the dike sections of the dike options. There after the surface areas are multiplied by the length of the dike. The lengths of the dike paths are determined with the measuring in QGis. The results are shown in Figure 25.

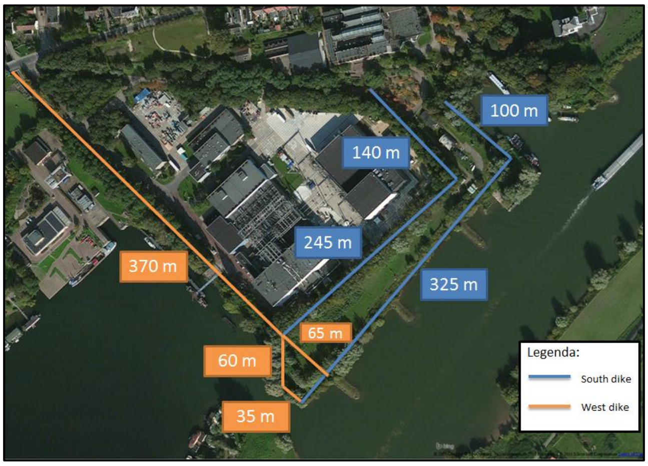


Figure 25: Length of the dike paths

These lengths are used for the determination of the costs. With the department for cost evaluation of Witteveen+Bos the costs for the 10 individual dikes are determined. These costs are then used to calculate the costs of the six design options. The costs of the individual dikes, the calculations and measurements can be found in Annex E1. The costs of the six dike design options are shown in Table 14.

Table 14: Cost calculation of dike designs

Design	Cost[€]
Design 1: Clay dike all around the foreland	1.541.002
Design 2: Sand dike all around the foreland	1.297.306
Design 3: Clay dike with room outside the dike	1.389.089
Design 4: Sand dike with room outside the dike	1.185.665
Design 5: Clay dike on terrain of KEMA Laboratories	845.294
Design 6: Sand dike on terrain of KEMA Laboratories	733.330

5. Multi-criteria analysis

To answer the question which dike design scores best on the given requirements, boundary conditions and wishes, a multi-criteria analysis is conducted. The criteria of the multi-criteria analysis are based on the requirements and wishes of KEMA Laboratories and are criteria on which the dike designs differ from each other.

5.1 Criteria

The criteria that will be used for the multi-criteria analysis are:

- Costs – In the multi-criteria analysis the construction costs of the different dike designs will be compared. Low costs give a high score on this criterion.
- Impact on terrain of KEMA Laboratories - A requirement from KEMA Laboratories is that all buildings at the terrain are retained. Around KEMA Laboratories trees and fences are placed. These will have to be moved if the dike will be constructed on the terrain. A design which is located on the terrain of KEMA Laboratories will have a negative score on this criterion.
- Extensibility – Due to uncertainty in high water levels, improved insights, the standard dike design can change over the years. If a dike scores high on extensibility it means that future changes are easily implemented.
- Sustainability – The sustainability of the designs is measured in the quantity of the required materials for the dike design
- Sensitivity for dike failure mechanisms piping and macro instability – how sensitive is a dike design to the failure mechanism piping or macro stability. In some designs, piping does not occur or macro instability is very unlikely to happen.

5.2 Analysis of dike designs

The six dike designs are analyzed how they score on the criteria.

- *Design 1: Clay dike all around the foreland*

The first dike design is a clay dike which is located all around the foreland. This dike design is the most expensive option. The location on the foreland has as result that is has little influence on the terrain of KEMA Laboratories. On the foreland there is much space for expanding the dike. This dike design is not very sustainable. A lot of material is required for this design. The dike design is sensitive for the failure mechanism piping, because piping can occur at the foreland.

- *Design 2: Sand dike all around the foreland made of sand*

The second design is a sand dike that is located at the same place as the first design. The sand dike is less expensive than the clay dike, but it is still one of the more expensive options. This dike design is not very sustainable. A lot of material is required for this design. A sand dike is more stable for the failure mechanism macro instability than a clay dike.

- *Design 3: Clay dike on foreland with room outside the dikes*

The third dike design is a clay dike on the foreland of KEMA Laboratories. This dike design is the second most expensive option. This is a more cost-efficient design, because it is still on the foreland, but requires less material for the building. For this reason this design is more sustainable than design 1 and 2, but it is still not very sustainable. Since the dike is located on the foreland of KEMA Laboratories, there is room for a possible expansion. Because the dike is on the foreland the design is sensitive for the failure mechanism piping.

➢ *Design 4: Sand dike on foreland with room outside the dikes*

The fourth dike design is a sand dike that is located on the same location as the third design. The sand dike is less expensive than the clay variant. A sand dike is more stable for the failure mechanism macro instability than a clay dike.

➢ *Design 5: Clay dike on terrain of KEMA Laboratories*

The fifth dike design is a clay dike on terrain of KEMA Laboratories. This option is one of the least expensive options and it has a good spatial integration. Less material has to be added because of the relative high ground levels. This dike design is a very sustainable option. Less material is needed than in the other designs. Nonetheless this dike design has much influence on the terrain of KEMA Laboratories. Besides this, a possible expansion of the dike in case of an increase of the safety requirements limited due to the little space on the site of KEMA Laboratories. The dike design is not sensitive for the failure mechanisms of piping and macro instability, due to the high ground levels at the terrain.

➢ *Design 6: Sand dike on terrain of KEMA Laboratories*

The sixth dike design is a sand dike on the same location as the fifth dike design. This design is the least expensive option of the six designs. This dike design scores also bad on the impact on the terrain of KEMA Laboratories. The dike design is not sensitive for the failure mechanisms of piping and macro instability, due to the high ground levels at the terrain.

5.3 Multi-criteria analysis

With the criteria and the different dike designs a multi-criteria analysis is conducted. The score of a criterion can be: - -, - , 0, + or ++. - - means that a designs scores very bad at this criterion and ++ means that the design scores very good at this criterion. 0 means that the criterion has no negative or positive influence on the analysis.

	Construction costs	Impact on terrain of KEMA Laboratories	Extensibility	Sustainability	Sensitivity for the failure mechanisms	Total score:
Design 1: Clay dike all around the foreland	-	+	+	--	-	**--**
Design 2: Sand dike all around the foreland	0	+	+	--	-	**-**
Design 3: Clay dike with room outside the dike	-	+	+	-	-	**-**
Design 4: Sand dike with room outside the dike	0	+	+	-	-	**0**
Design 5: Clay dike on terrain of KEMA Laboratories	+	--	-	+	+	**0**
Design 6: Sand dike on terrain of KEMA Laboratories	++	--	-	+	+	**+**

The dike designs that scores best on the criteria is the sixth dike design: sand dike on the terrain of KEMA Laboratories. The sand dike on the location of KEMA Laboratories is almost completely on the terrain of KEMA Laboratories. This dike requires the least amount of soil, because the terrain of KEMA Laboratories has a ground level of 13,9m +NAP. The dike design consists of two types of dike: a west dike located partly on the terrain of KEMA Laboratories and a south dike that is located completely on the terrain of KEMA Laboratories.

6. Discussion

For the dike design assumptions are made. The safety level for the dike design can be determined by the value for the flood risk (value of the area and flood probability). In this design we used a fixed value for the flood safety. In future research it is possible to differentiate the design for different flood safety levels to make a cost efficient design based on a full probabilistic design. The design of the dike is based on the flood safety of dike ring 47-1. It is possible that KEMA Laboratories demands a higher safety level for the dike. Also, in the cost calculation it is assumed that all materials are not available at the location and that they have to be shipped there from an extern location. If clay can be extracted easily from the surroundings of KEMA Laboratories, this could have influence on the cost calculation. There was little data available about the characteristics of the ground, which resulted in that the CSSM method that is described in “Handreiking ontwerpen met overstromingskansen” could not be used for the calculations. Therefor the macro stability is calculated with the Mohr-Coulomb model instead of the CSSM method. The designs all satisfy the minimum requirement with the lowest strength characteristics for the soils. For the dike design the wishes and requirements of other stakeholders have not been taken into account. More wishes and requirements could lead to different/more dike designs. At last the impact of the dike on the surroundings has not been taken in to account, for example the dike could have impact on the drainage of the area around the laboratories. The focus of the research was on the design of the dike.

The original solution designed by Witteveen+Bos was an emergency plan with big bags and sand bags. In case of a prediction for high water this plan could be executed. However this plan is a temporary solution and it had to be practiced regularly. For the bachelor thesis the option is research if this plan could be replaced with a more structural solution. In order to comply with the most recent insights and legislation this design is made with a semi-probabilistic design method. With the results of this research this plan could be replaced with a structural solution. For a relative low costs it is possible to place a dike, which is designed according to the most recent design method and that satisfies all norms and boundary conditions, on the location of KEMA Laboratories.

7. Conclusion

For the design of the dike all requirements, boundary conditions and wishes are met. Based on these requirements, boundary conditions and the failure mechanisms height, piping and macro stability six feasible designs were made. With the six designs a multi-criteria analysis is conducted. The design that came out best of the multi-criteria analysis is the sand dike located on the terrain of KEMA Laboratories. The sand dike is almost completely located on the terrain of KEMA Laboratories. This chosen dike requires the least amount of soil, because the terrain of KEMA Laboratories has a relative high ground level of at least 13,9m +NAP. The dike design consists of two types of dike: a west dike located partly on the terrain of KEMA Laboratories with a height of 15,7m +NAP and a south dike with a height of 15,1m + NAP, which is located completely on the terrain of KEMA Laboratories. The dike has a sand core and has a clay top layer, which makes it possible to grow a grass revetment on the dike. This option is the least expensive option that satisfies all boundary conditions. In consultation with KEMA Laboratories it has to be decided if this dike can be placed at this location. Based on the information that was available for this research this dike design is the best option. With low costs a dike can be constructed that is designed according to the most recent legislation and that satisfies all boundary conditions and requirements.

8. Recommendations

For following research more research is required for the requirements and wishes of KEMA Laboratories. The required flood risk for KEMA Laboratories has to be established for further research. I would recommend Witteveen+Bos to do more research and talk with KEMA Laboratories about more specific requirements and wishes. For an improvement of the cost calculation it is recommended to research if there is already clay or sand available at the location. If there is already material available this could influence the output of the cost calculation. Also there is more research required into the characteristics of the ground. For the CSSM method the characteristics in terms of stress and strain is required. If more data is available ab out the ground, the CSSM method can be used for the calculation of the macro stability. If more information about the soil at the terrain is known, the design can be optimized.

It is also recommended to do research about the wishes and requirements of other stakeholders of the area of KEMA Laboratories, like water boards, the municipalities and local residents. For further research it is also recommended to research the impact of dike on the area of KEMA Laboratories. The construction of a dike could have impact on the drainage of the terrain. If this influence is substantial this could be taken into account for the choice of a dike design.

9. Reference list

Actueel Hoogtebestand Nederland. (2014, March 05). *Nationaal Georegister.* Retrieved April 8, 2016, from Nationaal Georegister: http://nationaalgeoregister.nl/geonetwork/srv/dut/search#|c00b2d04-1e54-41c6-9b87-c226798361c0

Deltacommissaris. (2014, September 16). *Deltacommissaris.* Retrieved April 8, 2016, from Deltaprogramma 2015 Kaartbijlage 1b: http://www.deltacommissaris.nl/documenten/publicaties/2014/09/16/deltaprogramma-2015-kaartbijlage-1b

Deltares. (2015). *Werkwijze bepaling hydraulische ontwerprandvoorwaarden.* Deltares.

DNV GL. (2016). *DNV GL*. Retrieved April 12, 2016, from High-Power laboratory, Arnhem: https://www.dnvgl.com/services/high-power-laboratory-arnhem-4872

expertisenetwerk waterveiligheid. (2012). *Grondmechanisch schematiseren bij dijken.* Delft: Rijkswaterstaat, Verkeer en Leefomgeving.

Jansen MSc, M. (2015). *Water levels at KEMA and next steps.* Deventer: Witteveen+Bos.

Ministry of Infrastructure and the Environment. (2015). *Achtergrondrapport Ontwerpinstrumentarium 2014.* The Hague: Ministry of Infrastructure and the Environment.

Ministry of Infrastructure and the Environment. (2015). *Handreiking ontwerpen met overstromingskansen.* The Hague: Ministry of Infrastructure and the Environment.

Ministry of Transport, Public Works and Water Management. (2007). 9.3 Afvoer. In Rijkswaterstaat, *Technisch Rapport Ontwerpbelastingen voor het Rivierengebied* (p. 75). The Hague: Ministry of Transport, Public Works and Water Management.

Rijkswaterstaat. (2016, April). *Referentiewaarden Waterstanden.* Retrieved May 23, 2016, from Waternormalen: https://www.rijkswaterstaat.nl/water/waterdata-en-waterberichtgeving/metingen/waternormalen/index.aspx

Technische Adviescommissie voor de Waterkering. (2001). *Technisch Rapport Waterkerende Grondconstructies.* The Hague.

Technische Adviescommissie voor de Waterkering. (2007). *Addendum Deel A - Technisch Rapport Waterkerende Grondconstructies .* The Hague: Rijkswaterstaat.

Technische Adviescommissie voor de Waterkeringen. (1996). *Technisch Rapport Klei voor Dijken.* Delft: Technische Adviescommissie voor de Waterkeringen.

Technische Adviescommissie voor de Waterkeringen. (1999). *Technisch Rapport Zandmeevoerende wellen.* Delft: Technische Adviescommissie voor de Waterkeringen.

Technische Adviescommissie voor de Waterkeringen. (2004). *Technisch Rapport Waterspanningen bij dijken.* The Hague: Technische Adviescommissie voor de Waterkeringen.

Van Manen, S. E., & Brinkhuis, M. (2005). Quantitative flood risk assessment for Polders. *Elsevier, 90*(2-3), 229-237.

Vrijling, J. (2000). Probabilistic design of water defense systems in The Netherlands. *Elsevier, 74*(3), 337-344.

Walker, W. E., Abrahamse, A., Bolten, J., Kahan, J. P., Van de Riet, O., Kok, M., & Den Braber, M. (1994). A Policy Analysis of Dutch River Dike Improvements: Trading Off Safety, Cost, and Environmental Impact. *Operations Research*, 823-836.

Annexes

A. Hydraulic boundary conditions

The hydraulic boundary conditions are determined with the "Werkwijze bepaling hydraulische ontwerprandvoorwaarden" of Deltares (Deltares, 2015). In order to determine the hydraulic boundary conditions first the water levels are determined. After that, the crest height is determined. First the hydraulic load on the dike is simulated with "Hydra Zoet". "Hydra Zoet" is a probabilistic model that combines wind and discharge scenario' of 'Rijkswaterstaat' and is developed for the testing and determination of the hydraulic boundary conditions of water-retaining structures near fresh water with a semi-probabilistic method. With the water levels that are simulated in "Hydra Zoet" and the simulated hydraulic load on the dike, the required crest height of the dike can be determined with the program "PC Overslag" of "Rijkswaterstaat". For the area around KEMA Laboratories overtopping is not allowed so the maximum overtopping discharge of the dike is set on 0.1 L/s/m.

1. Location

Various locations of the Lower-Rhine are available in 'Hydra-Zoet'. There is no data available on the exact location of KEMA Laboratories, so the data of a location upstream of the KEMA is used. The data of location 10 on dike ring 47 at kilometer marker 883-884 is used (shown in Figure 26 in yellow). This location is 1.8 kilometers upstream of KEMA Laboratories. The fetch lengths of the area of the KEMA are used as an input for location 10.

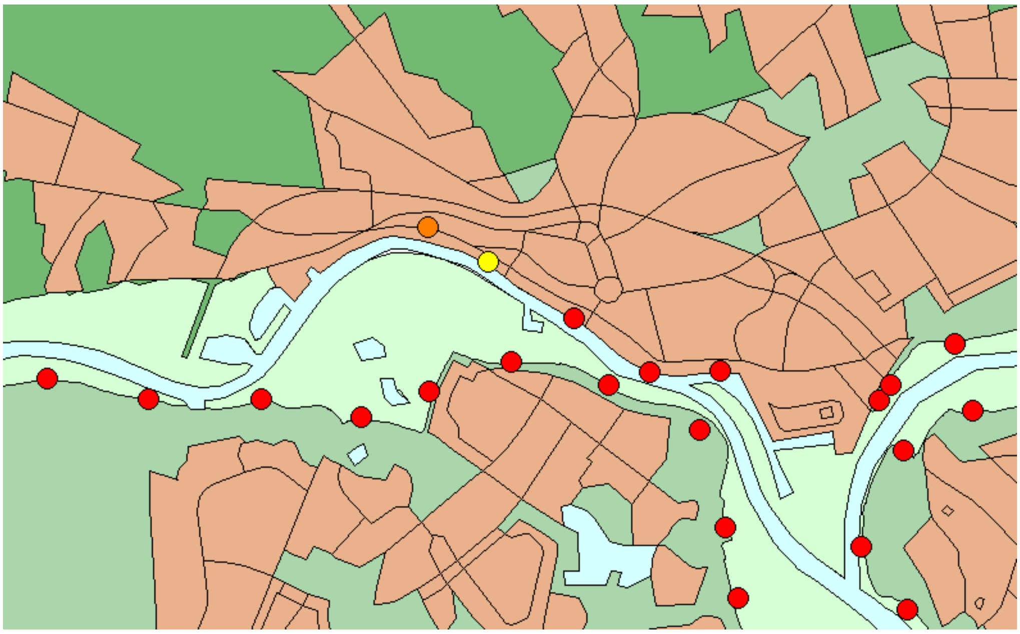


Figure 26: Location 10 (yellow) is used for the simulations

2. Simulation of water levels

First the water levels are simulated in "Hydra Zoet". The water levels are simulated for six frequencies: 1/1.000, 1/1.250, 1/2.000, 1/4.000, 1/10.000 and 1/20.000 years. The frequency 1/20.000 years is the lowest frequency that can be simulated for which the results are validated. It is possible to determine the water levels for lower frequencies by extrapolating the results of higher frequencies. But since these results are not validated and there is limited time for the research, the lower bound for the simulations for return period is 1/20.000 years. "Hydra Zoet" simulates the water levels for 10 scenarios. The following scenarios are preset in the database of "Hydra Zoet"

1. Average 2050
2. Average+ 2050
3. Veerman 2050
4. Warm 2050
5. Warm+ 2050
6. Average 2100
7. Average+ 2100
8. Veerman 2100
9. Warm 2100
10. Warm+ 2100

The results of the simulated water levels of the 10 scenarios are shown in Figure 27.

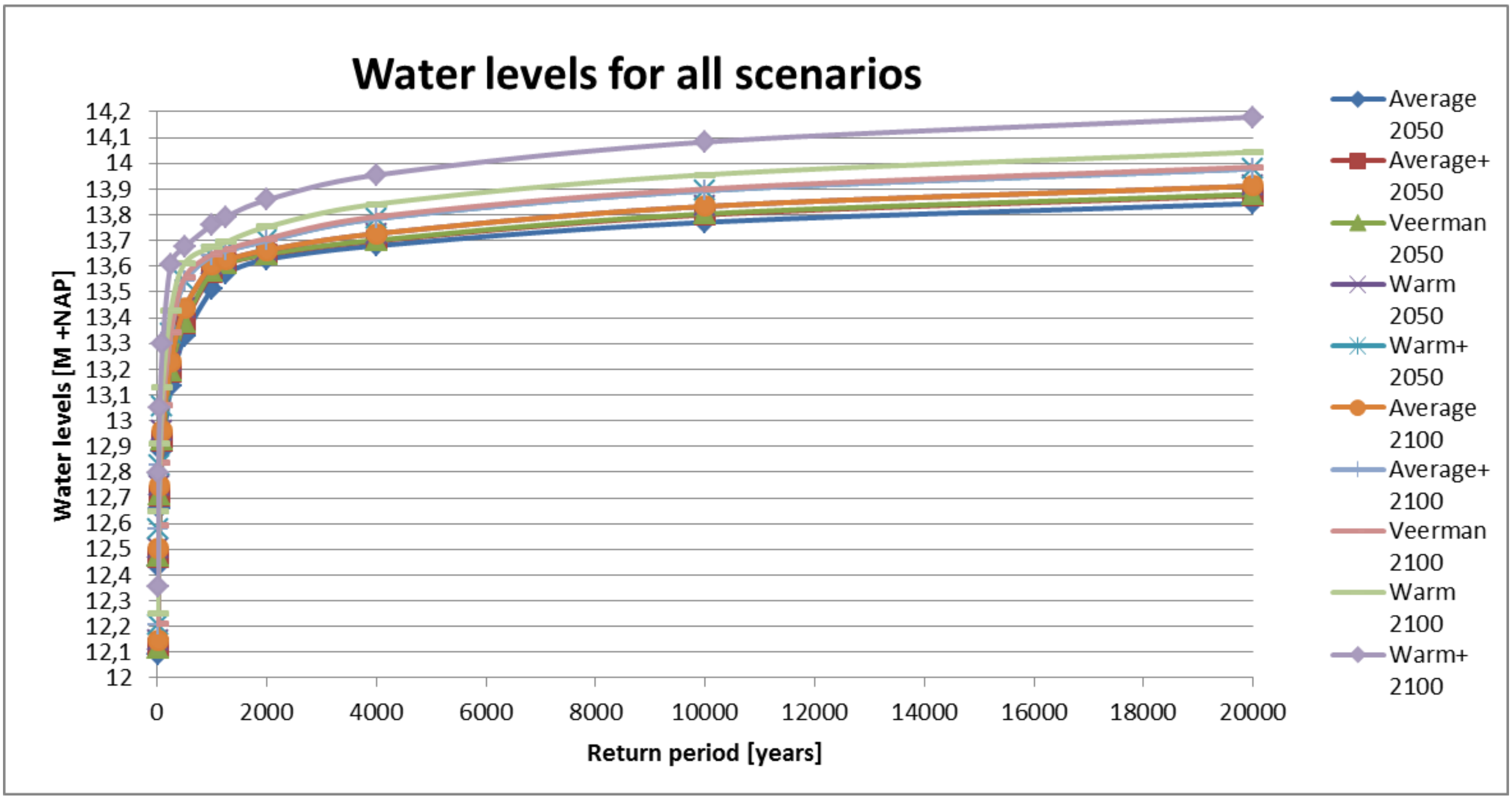


Figure 27: Simulated water levels for different scenarios

The scenario warm+ 2100 gives the highest water levels and since the design has to be the most conservative this scenario is used for the simulation. The water levels are used to determine the crest height of the dike. Usually by the design of dikes the water levels of scenario average+ are used as the design water levels (Ministry of Transport, Public Works and Water Management, 2007). In this case there is chosen to choose the most extreme scenario to make a robust design. Future expansions of the dike (for example in case of a higher norm for the dike) are hard to realize due to the limited space and the high cost of such an expansion.

Simulated water levels for scenario warm+

The simulated water levels of location 10 in the Lower Rhine are shown in Table 15.

Table 15: Return periods and simulated water levels for warm+ scenario

Return period (years)	Water level (m +NAP)
10	12,355
25	12,798
50	13,049
100	13,299
250	13,608
500	13,675
1000	13,761
1250	13,792
2000	13,858
4000	13,955
10000	14,083
20000	14,180

Finally the simulated water levels are adapted to the slope of the river and an uncertainty addition is added to the water levels. The uncertainty addition for rivers according to "Ontwerpinstrumentarium 2014" is +0,30m (Deltares, 2015). Since the water levels are simulated for location 10 which is upstream of KEMA Laboratories, the water levels are corrected for the slope of the river. Location 10 is located 1.8 km upstream of KEMA Laboratories, which is shown in Figure 28. The slope of the Lower Rhine is 0,10m/km. This means that the simulated water levels have to be corrected with -0,18m. The results are shown in Table 16.

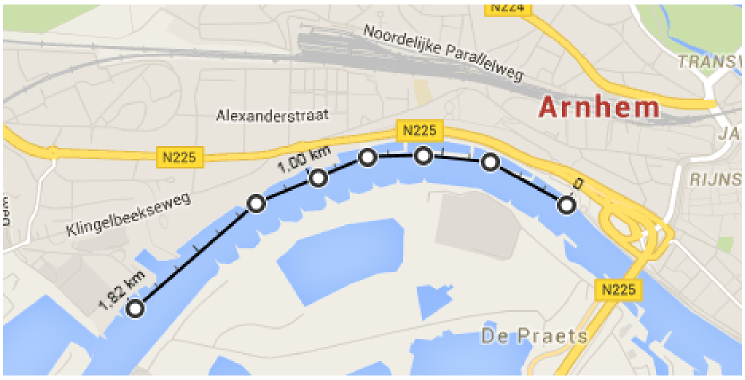


Figure 28: Location 10 upstream of KEMA Laboratories

Table 16: Corrected water levels with uncertainty addition and slope

Return period (years)	Simulated water levels (m +NAP)	Corrected water levels (m +NAP)
10	12,355	12,475
25	12,798	12,918
50	13,049	13,169
100	13,299	13,419
250	13,608	13,728
500	13,675	13,795
1000	13,761	13,881
1250	13,792	13,912
2000	13,858	13,978
4000	13,955	14,075
10000	14,083	14,203
20000	14,180	14,300

3. Simulation of hydraulic load ('Hydraulisch belasting niveau')

The hydraulic loads on the area of KEMA Laboratories are simulated on two locations: the south- and the west side of KEMA Laboratories. Since the locations have another orientation and fetch lengths with relation to the direction of the waves, there are different wave heights at the two locations. For the simulation of the wave heights two profiles are added to "Hydra Zoet". The hydraulic load will be calculated for a 1:2-profile and a 1:3-profile.

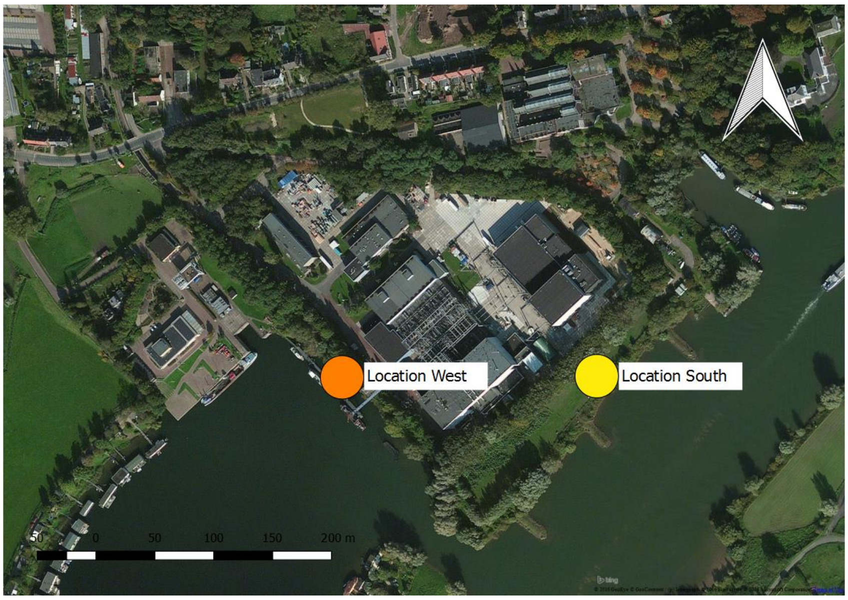


Figure 29: Location West and Location South on area of KEMA Laboratories

The hydraulic load is simulated on location 10 with the effective fetch lengths. In order to simulate the wave heights at the Location of KEMA Laboratories the effective fetch length of the wind at location 10 is adjusted to the effective fetch lengths of the location of KEMA Laboratories. The fetch lengths are estimated in QGis with the measuring tool. The fetch length is the length of water over which a given wind has blown. With the height map in QGis the effective fetch lengths are determined. The area around the Lower Rhine is surrounded with dikes. For the effective lengths are determined for a high water situation. In this situation the river forelands around the Lower Rhine are flooded. The effective fetch lengths that are used for the simulation are shown in Table 17. The characteristic soil level is set on 10 m +NAP. "Hydra Zoet loads in the data from the profile of the area around the point. By setting the characteristic soil level op 10 m +NAP, it ignores the profile data. The calculated wave heights are simulated on another location than the location of KEMA Laboratories, so it was not possible to use the preset ground levels of Hydra Zoet. The effective lengths are adapted to the location of KEMA Laboratories. The lengths are estimated in QGis.

Table 17: Effective fetch lengths by wind directions

Wind direction	Characteristic soil level [m +NAP]	Effective fetch length [m]
NNE	10	500
NE	10	1440
ENE	10	1700
E	10	2225
ESE	10	1567
SE	10	1753
SSE	10	1300
S	10	1118
SSW	10	1442
SW	10	1800
WSW	10	2485
W	10	875
WNW	10	673
NW	10	100
NNW	10	100
N	10	100

With the adapted effective fetch lengths in location 10 for the location of KEMA Laboratories, four simulations have been performed with "Hydra Zoet" to simulate the hydraulic loads:

- Location south – profile 1:2
- Location south – profile 1:3
- Location west – profile 1:2
- Location west – profile 1:3

The dike normal, which is the angle between north and the normal line on the dike, on location south is 130° and on location west it is 224°. This is shown in Figure 30.

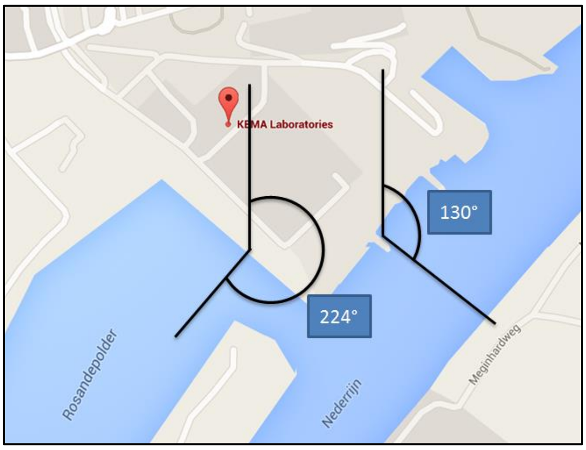


Figure 30: Dike normal on location south and west

The results of the simulations for hydraulic load "Hydra Zoet" are used in PCOverslag to calculate the required crest height. The requirement for the fail probability for height is 1/4.170 year, so for the determination of the required crest height the results of the wave conditions for a return period of 4.000 year are used.

B. Geometric boundary conditions

The current geometry of the area around KEMA Laboratories is determined in QGis. A section of the foreland is made and the height of these sections is shown below the map. The results are shown in Figure 31 and Figure 32.

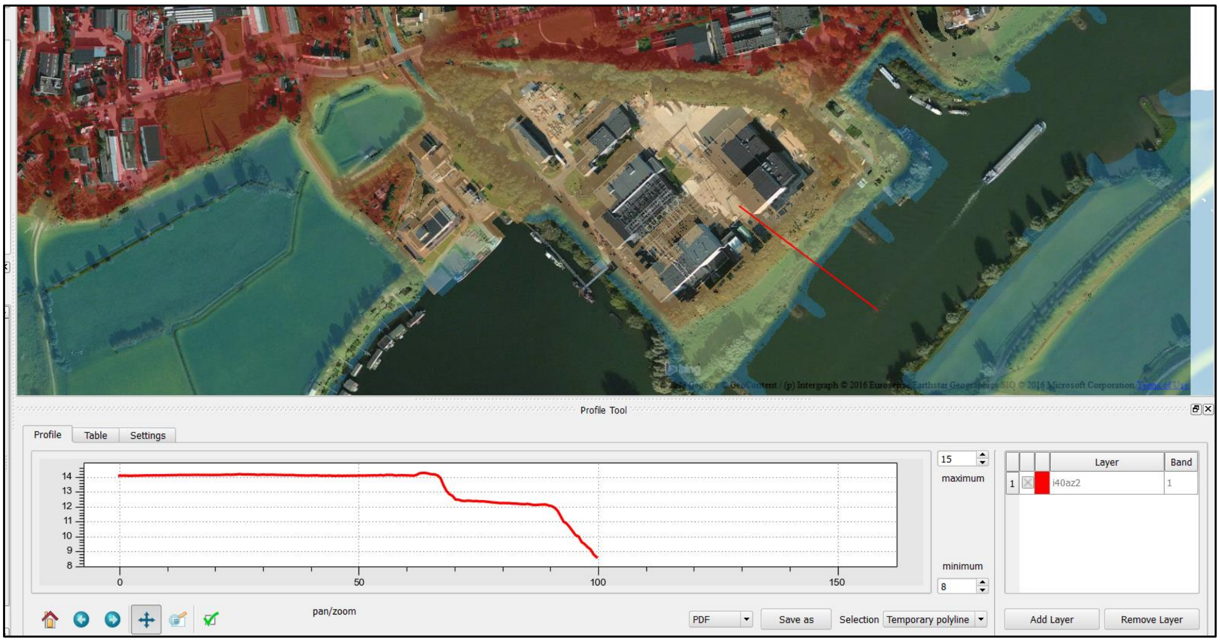


Figure 31: Section of current geometry on location south

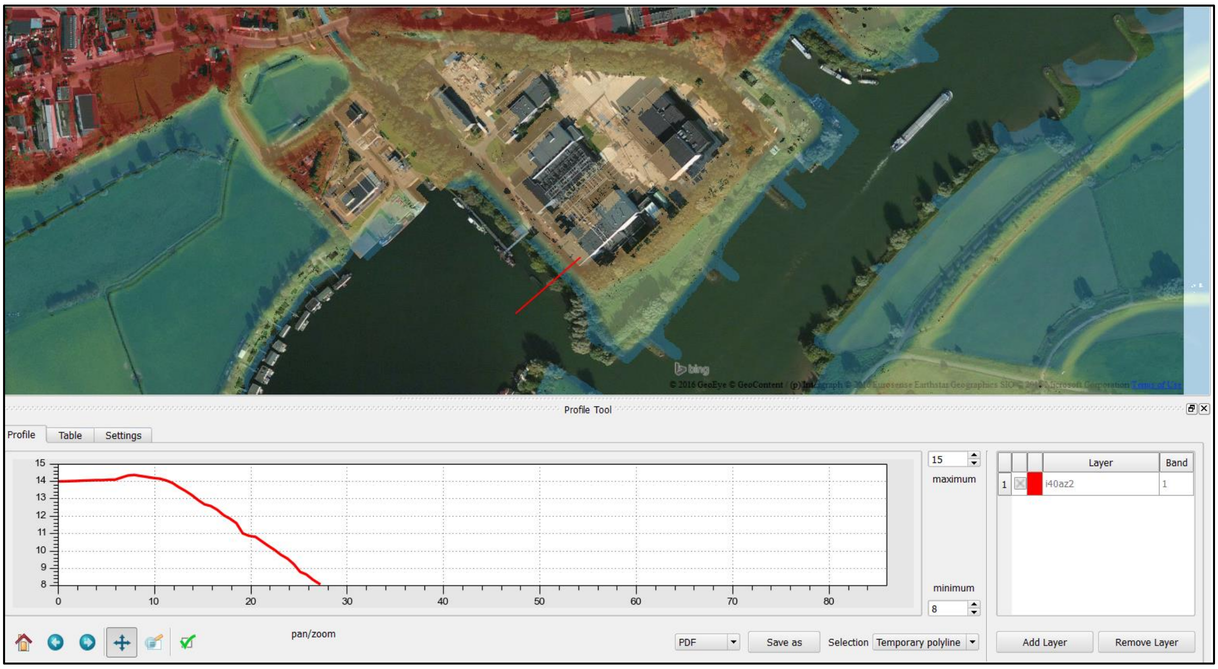


Figure 32: Section of current geometry of location west

C. Geotechnical boundary conditions

1. Soil borings at location KEMA Laboratories

The used soil borings B40A0179 and B40A0374 are shown in Figure 33.

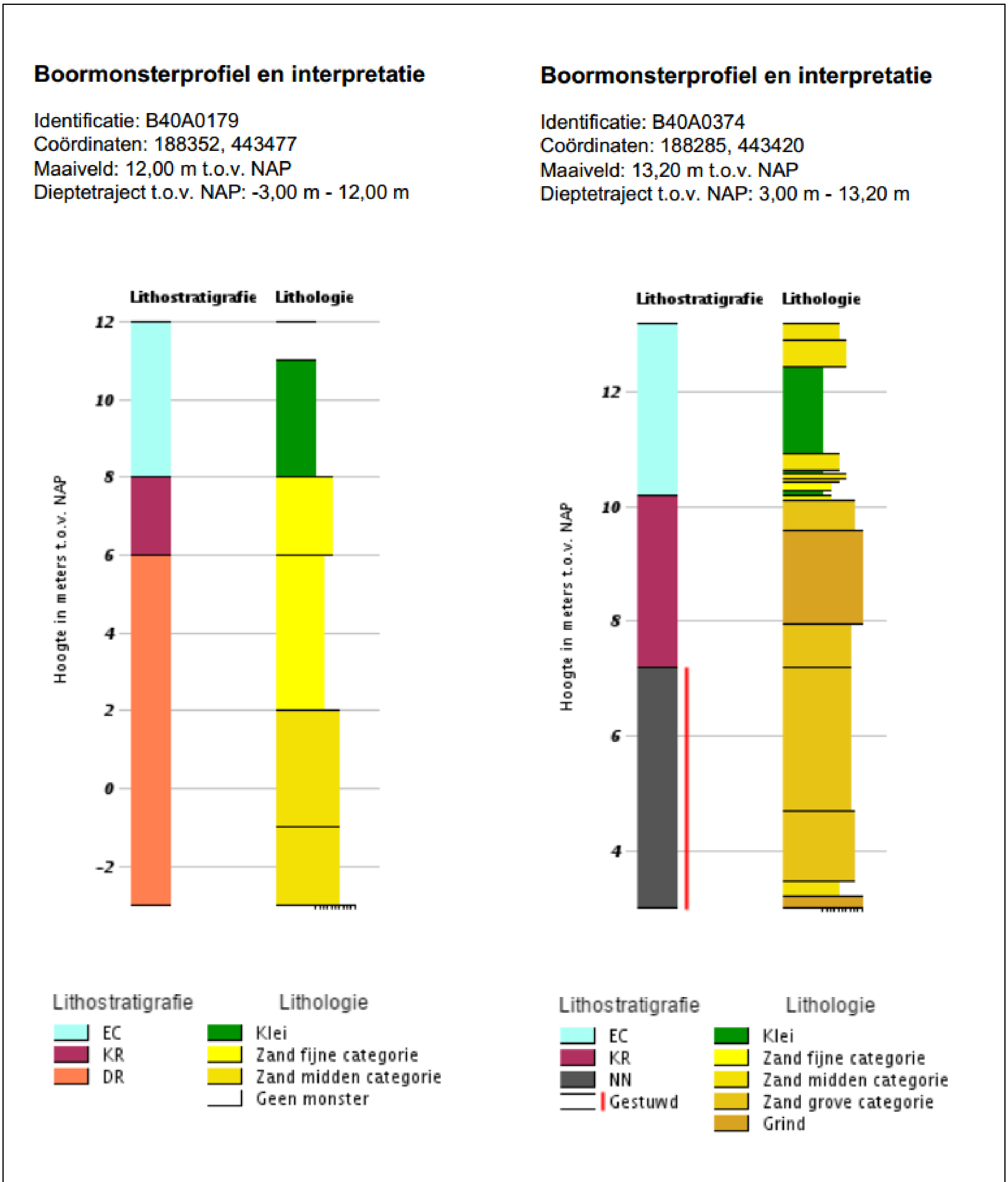


Figure 33: Soil boring B40A0179 and B40A0179

2. Thickness of aquifer

For the determination of the thickness of the aquifer for the calculations for piping the deeper soil boring, shown in Figure 34, is used. With a section of the ground at KEMA Laboratories the height of the lower bound of the sediments ("Gestuwde afzetting") is estimated. This is shown in Figure 35. . The thickness of the aquifer is estimated on 21m.

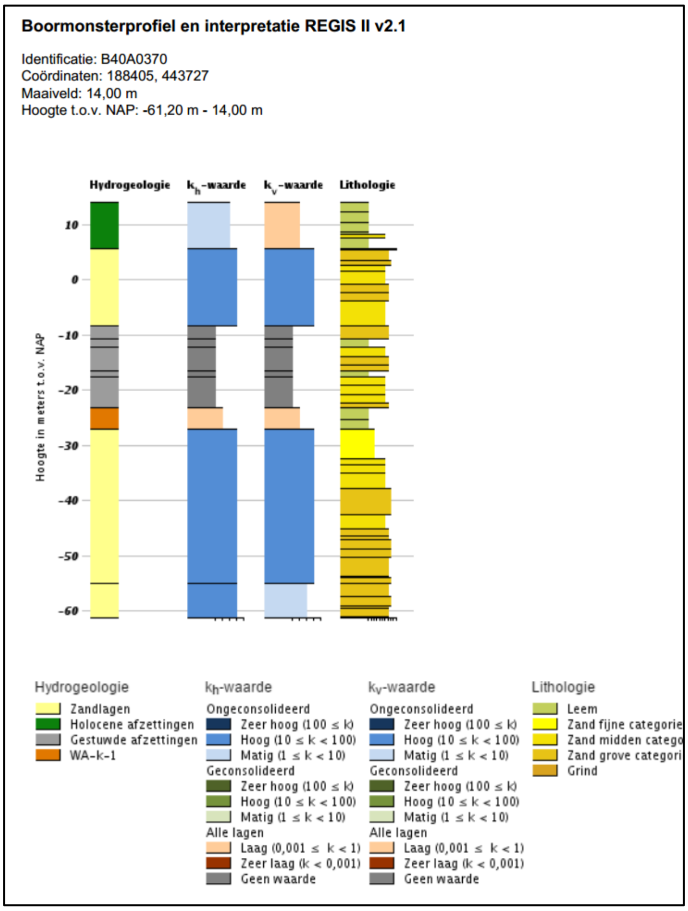


Figure 34: Deeper boring at location of KEMA Laboratories

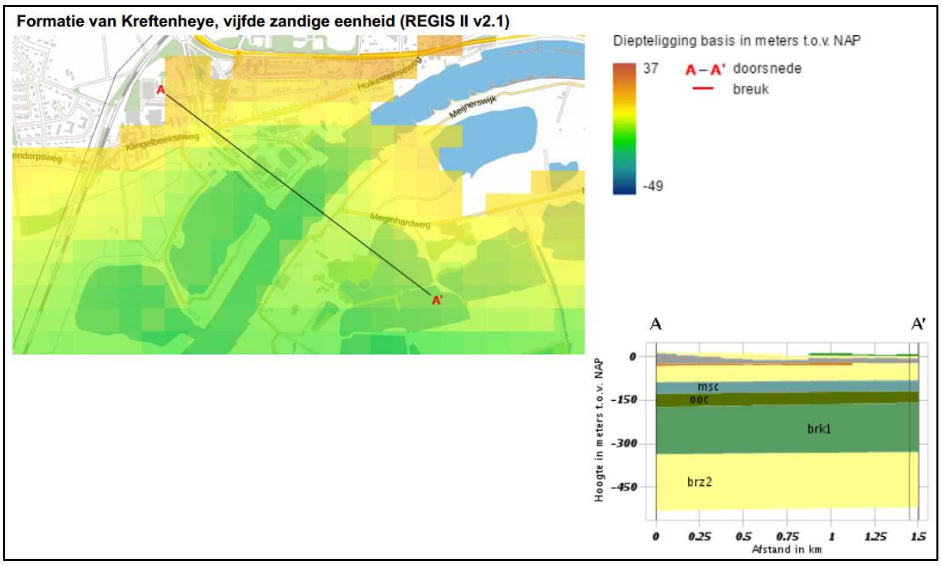


Figure 35: Section of sand layers under terrain of KEMA Laboratories

3. Table 2b. NEN 1997-1 +C

Table 2b from the NEN 1997 is used for the characteristics of the soil.

Tabel 2.b — Karakteristieke waarden van grondeigenschappen

Grondsoort			Karakteristieke waarde[a] van grondeigenschap											
Hoofd-naam	Bijmengsel	Consis-tentie[b]	γ[c] kN/m³	γ_{sat} kN/m³	q_c[d g] MPa	C'_p[g]	C'_s	$C_c/(1+e_0)$[g] [-]	C_α[f] [-]	$C_{sw}/(1+e_0)$[g] [-]	E_{100}[g h] MPa	φ'[g] Graden	c' kPa	c_u kPa
Grind	Zwak siltig	Los	17	19	15	500	∞	0,0046	0	0,0015	45	32,5	0	
		Matig	18	20	25	1000	∞	0,0023	0	0,0008	75	35,0	0	n.v.t.
		Vast	19 20	21 22	30	1200 1400	∞	0,0019 0,0016	0	0,0006 0,0005	90 105	37,5 40,0	0	
	Sterk siltig	Los	18	20	10	400	∞	0,0058	0	0,0019	30	30,0	0	
		Matig	19	21	15	600	∞	0,0038	0	0,0013	45	32,5	0	n.v.t.
		Vast	20 21	22 22,5	25	1000 1500	∞	0,0023 0,0015	0	0,0008 0,0005	75 110	35,0 40,0	0	
Zand	Schoon	Los	17	19	5	200	∞	0,0115	0	0,0038	15	30,0	0	
		Matig	18	20	15	600	∞	0,0038	0	0,0013	45	32,5	0	n.v.t.
		Vast	19 20	21 22	25	1000 1500	∞	0,0023 0,0015	0	0,0008 0,0005	75 110	35,0 40,0	0	
	Zwak siltig, kleiig		18 19	20 21	12	450 650	∞	0,0051 0,0035	0	0,0017 0,0012	35 50	27,0 32,5	0	n.v.t.
	Sterk siltig, kleiig		18 19	20 21	8	200 400	∞	0,0115 0,0058	0	0,0038 0,0019	15 30	25,0 30,0	0	n.v.t.
Leem[e]	Zwak zandig	Slap	19	19	1	25	650	0,0920	0,0037	0,0307	2	27,5 30,0	0	50
		Matig	20	20	2	45	1300	0,0511	0,0020	0,0170	3	27,5 32,5	1	100
		Vast	21 22	21 22	3	70 100	1900 2500	0,0329 0,0230	0,0013 0,0009	0,0110 0,0077	5 7	27,5 35,0	2,5 3,8	200 300
	Sterk zandig		19 20	19 20	2	45 70	1300 2000	0,0511 0,0329	0,0020 0,0013	0,0170 0,0110	3 5	27,5 35,0	0 1	50 100
Klei	Schoon	Slap	14	14	0,5	7	80	0,3286	0,0131	0,1095	1	17,5	0	25
		Matig	17	17	1,0	15	160	0,1533	0,0061	0,0511	2	17,5	5	50
		Vast	19 20	19 20	2,0	25 30	320 500	0,0920 0,0767	0,0037 0,0031	0,0307 0,0256	4 10	17,5 25,0	13 15	100 200
	Zwak zandig	Slap	15	15	0,7	10	110	0,2300	0,0092	0,0767	1,5	22,5	0	40
		Matig	18	18	1,5	20	240	0,1150	0,0046	0,0383	3	22,5	5	80
		Vast	20 21	20 21	2,5	30 50	400 600	0,0767 0,0460	0,0031 0,0018	0,0256 0,0153	5 10	22,5 27,5	13 15	120 170
	Sterk zandig	-	18 20	18 20	1,0	25 140	320 1680	0,0920 0,0164	0,0037 0,0007	0,0307 0,0055	2 5	27,5 32,5	0 1	0 10
	Organisch	Slap	13	13	0,2	7,5	30	0,3067	0,0153	0,1022	0,5	15,0	0 1	10
		Matig	15 16	15 16	0,5	10 15	40 60	0,2300 0,1533	0,0115 0,0077	0,0767 0,0511	1,0 2,0	15,0	0 1	25 30
Veen	Niet voorbelast	Slap	10 12	10 12	0,1	5 7,5	20 30	0,4600 0,3067	0,0230 0,0153	0,1533 0,1022	0,2 0,5	15,0	1 2,5	10 20
	Matig voorbelast	Matig	12 13	12 13	0,2	7,5 10	30 40	0,3067 0,2300	0,0153 0,0115	0,1022 0,0767	0,5 1,0	15,0	2,5 5	20 30
Variatiecoëfficiënt *v*			0,05		–	0,25					0,10		0,20	

Zie vervolg

D. Design calculations

1. Calculations height

The corrected water levels and the wave conditions simulated in “Hydra Zoet” are used as input in PCOverslag to determine the required crest height. The maximum allowed overtopping discharge is set on 0.1L/s/m. The required crest height is calculated on two locations: the south-location and the west-location.

The input that is required in PCOverslag is:

Input	Definition	Unit
Hmo	Significant wave height	Meters
β	Wave direction in degrees (angle between dike normal and wave direction with respect to North)	Degrees
Tm-1	The spectral wave period	Seconds
SWL	Water level	Meters
tsm	Normative storm duration	Seconds
Tm	Average wave period	Seconds

Location South - input data and results:

For location south the dike normal is 130°. See Figure 30 for explanation.

Input	Profile 1:2	Profile 1:3
Hmo	0,51 m	0,53 m
β	73°	73°
Tm-1	2,4 s	2,5 s
SWL	14,075 m	14,075 m
tsm	20000	20000 s
Tm	2,0 s	2,0 s
Required crest height	**15,377 m**	**15,092 m**

Location West- input data and results:

For location south the dike normal is 224°. See Figure 30 for explanation.

Input	Profile 1:2	Profile 1:3
Hmo	0,67 m	0,66 m
β	24	24
Tm-1	2,8 s	2,8 s
SWL	14,075 m	14,075 m
Normative storm duration	20000 s	20000 s
Tm	2,0 s	2,0 s
Required crest height	**16,259 m**	**15,658 m**

2. Calculations piping

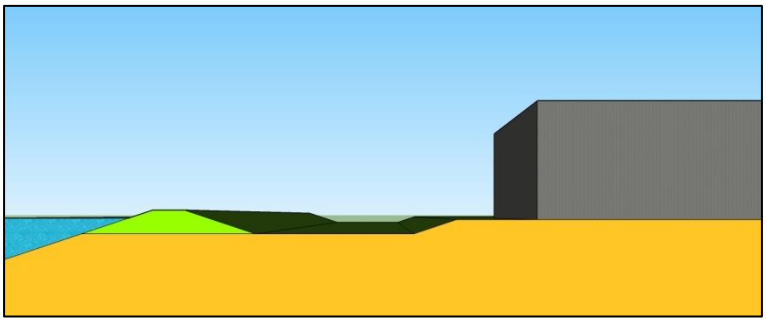
For the calculations of piping and heave the soil boring B40A0374 is used. This is the most conservative assumption. The boring has the highest probability on which piping and heave can occur. This data is used to determine the top layer that gives the ground pressure. The ground data of the soil boring is shown in Table 18.

Table 18: Soil structure at location B40A0374

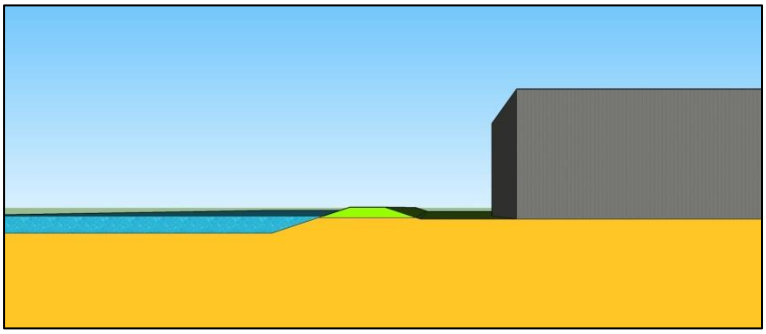
From [m +NAP]	To [m +NAP]	Soil type
13,20	12,90	Sand
12,90	12,44	Sand, gravelly
12,44	10,94	Clay
10,94	10,65	Sand
10,65	10,10	Sand, clayey
10,10	9,60	Sand, gravelly
9,60	7,94	Gravel
7,94	3,48	Sand, gravelly
3,48	3,20	Sand
3,20	3,00	Gravel

There are two possible locations for the dike:

- Dike on the foreland:



- Dike on the site of KEMA Laboratories:



Uplifting

In order to check if the ground will lift under the water pressure the ground pressure and the water pressure are calculated. Lifting of the ground will occur if $\frac{ground\ pressure}{water\ pressure} < 1{,}0$. If this occurs, then the dike has to be checked for the failure mechanism piping. The lifting of the ground will be checked with the following formula (Ministry of Infrastructure and the Environment, 2015):

$$\frac{ground\ pressure}{water\ pressure} = \frac{0{,}9(\gamma_{nat} - \gamma_w)d_x}{1{,}0\gamma_w\left(\varphi_{z,x,GHW} - h_{p,x}\right) + 1{,}5\gamma_w\left(\varphi_{z,x,MHW} - \varphi_{z,x,GHW}\right)} \geq 1{,}0$$

In which:

- γ_{nat}= wet volumetric weight (kN/m^3)
- γ_w= volumetric weight of water (kN/m^3)
- $\varphi_{z,x,GHW}$=rise in the heave zone in the aquifer at the average annual high water (m +NAP)
- $\varphi_{z,x,MHW}$= rise in the heave zone in the aquifer at the normative conditions (m +NAP)
- $h_{p,x}$= polder level in the heave zone (m +NAP)

The $\varphi_{z,x,GHW}$ is for the Lower Rhine near Arnhem 11,35 m +NAP. This is the water level with an exceedance frequency of 1 year (Rijkswaterstaat, 2016).

$\varphi_{z,x,MHW}$ is the water level that occurs 1/1000 years. The maximum accepted chance of failure for dike ring 47-1 is 1/1000 years. According to “Handreiking ontwerpen met overstromingskansen” is the design water level for piping similar to the water level with an exceedance probability similar to the maximum accepted chance of failure. So the design water level is 13,881 m +NAP.

$h_{p,x}$ is the polder level. For the two locations the polder level different. For the dike on the foreland the polder level is 12,1 m +NAP and for the dike on the location of KEMA Laboratories the polder level is 13,9 m +NAP.

Calculations uplifting

In this annex the calculations of uplifting can be found. Uplifting is calculated on two locations: for the dike on the foreland and for the dike on the terrain of KEMA Laboratories.

➢ Location 1: dike on the foreland

Ground pressure:

Under the ground levels is 1,16 m of clay. For the characteristic values of the ground characteristics, Table 2b of NEN 1997 is used. This can also be found in Annex B3

$\gamma_{nat} = 17\ kN/m^3\ (clay, clean, moderate)$

$\gamma_w = 10\ kN/m^3$

$\varphi_{z,x,MHW} = 13{,}881\ m + NAP$

$h_{p,x} = 12{,}1\ m + NAP$

$$\frac{ground\ pressure}{water\ pressure} = \frac{0{,}9(\gamma_{nat} - \gamma_w)d_x}{1{,}0\gamma_w(\varphi_{z,x,GHW} - h_{p,x}) + 1{,}5\gamma_w(\varphi_{z,x,MHW} - \varphi_{z,x,GHW})} \geq 1{,}0$$

$ground\ pressure = 0{,}9 * (17 - 10) * 1{,}16 = 7{,}308\ kN/m^2$

Water pressure:

$water\ pressure = 1{,}0 * 10 * (11{,}35 - 12{,}10) + 1{,}5 * 10 * (13{,}881 - 11{,}35) = 30{,}465$

Check for uplifting:

$\frac{ground\ pressure}{water\ pressure} = \frac{7{,}308}{30{,}465} = 0{,}24\ and\ is\ < 1{,}0$

This means that uplifting will occur and that piping is a relevant failure mechanism.

➢ Location 2: dike on the site of KEMA Laboratories

Ground pressure:

Under the ground levels is 1,46 m of sand and 1,50 m of clay.

$\gamma_{nat,clay} = 17\ kN/m^3\ (clay, clean, moderate)$

$\gamma_{nat,sand} = 20\ kN/m^3\ (sand,\ moderate)$

Ground pressure of sand: $ground\ pressure = 0{,}9 * (20 - 10)1{,}46 = 13{,}14\ kN/m^2$

Ground pressure of clay: $ground\ pressure = 0{,}9 * (17 - 10)1{,}50 = 9{,}45\ kN/m^2$

Total ground pressure: $13{,}14 + 9{,}45 = 22{,}59 kN/m^2$

Water pressure:

$water\ pressure = 1{,}0 * 10 * (11{,}35 - 13{,}9) + 1{,}5 * 10 * (13{,}881 - 11{,}35)$ =12,465

Check for uplifting:

$\frac{ground\ pressure}{water\ pressure} = \frac{22{,}59}{12{,}465} = 1{,}81\ and\ is > 1{,}0$

This means that piping through a deeper sand layer is not possible. Nonetheless there is a layer of sand under the ground level. If the dike is a clay dike, the possibility that piping can occur has to be checked. If the dike is a sand dike, the possibility for piping will not be checked, since there is a sand-on-sand situation in which piping does not occur. In this case however the water level outside the dike is lower than the ground level at the terrain of KEMA Laboratories. Since there is no gravity flow possible in this situation, piping cannot occur.

Calculations seepage length

In order to determine the seepage length, first the factor of schematization for piping needs to be determined. In order to take uncertainties of the surrounding of KEMA Laboratories into account a 'factor of schematization for piping" is determined. The factor of schematization γ_b is estimated with the method described in the technical report "Grondmechanisch schematiseren bij Dijken" (expertisenetwerk waterveiligheid, 2012). The seepage length is calculated with the formulas of Sellmeijer.

The used formulas from Sellmeijer are:

$$H_{c,sellmeijer} = F_{res} * F_{scale} * F_{geo} * L$$

$$F_{res} = \frac{\gamma_p'}{\gamma_w} * (\eta * \tan\theta)$$

$$F_{scale} = \frac{d_{70m}}{\sqrt[3]{\kappa * L}} * \left(\frac{d_{70}}{d_{70m}}\right)^{0,4}$$

$$F_{geo} = 0,91 * \left(\frac{D}{L}\right)^{\frac{0,28}{\left(\frac{D}{L}\right)^{2,8} - 1} + 0,04}$$

In which:

L = horizontal seepage length (m)
D = thickness of the aquifer (m)
d70 = 70-percentile value of the grain-size distribution (-)
d = vertical seepage length (m)
fd = d-factor (-)
θ = Angle of repose (°)
k = permeability of sand layer (m/s)
κ = intrinsic permeability (m^2)
η = coefficient of White (-)
γ_p= volumetric weight of grains under water (kN/m^3)
γ_w= volumetric weight of water (kN/m^3)
ΔH = critical fall over the dike

Factor for schematization for piping

In order to determine the seepage length, the factor of schematization for piping needs to be determined. According to the method of "Grondmechanisch schematiseren bij Dijken" (expertisenetwerk waterveiligheid, 2012) the factor of schematization is estimated on a certain value. With this value the seepage length will be calculated. There after different scenarios are created and calculated. The factor of schematization is estimated based on the following scenarios:

1. The ground level on the inside of the dike is 0,3 m lower
2. The layer of clay is local 0,5 m thinner
3. The aquifer is 35 m thick instead of 21 m
4. Locally the layer of clay is missing

For the determination of the schematization factor the design requirement (F_{pip}) is calculated. The design requirement (F_{pip}) is calculated with the following formulas (expertisenetwerk waterveiligheid, 2012):

$$F_{pip} = \frac{\Delta H_c}{\Delta H_{optr}}$$

$$\Delta H_c = \frac{1}{1{,}2} H_{c,sellmeijer}$$

$$\Delta H_{optr} = H_{buiten} - H_{binnen} - 0{,}3d$$

In which:

$\Delta H_c = the\ critical\ fall\ over\ the\ dike$
$\Delta H_{optr} = occuring\ gravity\ flow$
$H_{buiten} = height\ outer\ water\ level$
$H_{binnen} = height\ ground\ level\ inside\ the\ dike$
$d = vertical\ seepage\ lenght$

For every scenario the difference of the F_{pip} is calculated. Table 3.6 of technical report "Grondmechanisch schematiseren bij Dijken", which is shown in Figure 36, is used for the calculation of the required factor of schematization. With this table the required factor of schematization is deduced. If this factor of schematization is lower than the first estimated factor of schematization the first assumption satisfies. This calculation is made for all the scenarios. With this method the required factor of schematization is determined.

Verschil in veiligheidsfactor t.o.v. basis-schematisering: ΔF_{pip}	Som van kansen van afwijkende scenario's $\Sigma P(S_i)$	$\gamma_{b,\,pip}$
-0,40 tot -0,30	< 30%	1,38
	< 10%	1,36
	<3%	1,33
	<1%	1,31
	< 0,3%	1,28
-0.30 tot -0,20	< 30%	1,28
	< 10%	1,26
	<3%	1,23
	<1%	1,21
	< 0,3%	1,18
-0.20 tot -0,10	< 30%	1,18
	< 10%	1,16
	<3%	1,13
	<1%	1,11
	< 0,3%	1,08
-0.10 tot 0	< 0,3%	1,01

Tabel 3.6: Schematiseringfactoren voor het (deel)mechanisme piping

Figure 36: Tabel 3.6 of "Grondmechanisch schematiseren bij Dijken"

Calculation of the scenarios

- Scenario 0: current situation

For the 0-scenario the factor of schematization is estimated on 1,20. With this value the seepage length will be calculated according to the formulas of Sellmeijer. The input that is used for the calculation of the seepage length is shown in Table 19.

Table 19: Input calculation of seepage length

Input	Symbol	Unit	Input value
Horizontal seepage length	L	m	1
Thickness of aquifer	D	m	21
70-percentile value of the grain-size distribution	d70	-	2,10E-04
Vertical seepage length	d	m	1,16
d-factor	fd	-	0,3
Rolling resistance	θ	°	37
Permeability of sand layer	k	m/s	2,85E-04
Intrinsic permeability	κ	m²	3,85E-11
coefficient of White	η	-	0,25
volumetric weight of grains under	γp	kN/m³	16
volumetric weight of water	γw	kN/m³	10
Outside water level	γw	kN/m³	13,881
Height outlet	MHW	m +NAP	12,10

The formulas that are used for the calculation of the seepage length (L) are shown below:

$$H_{c,sellmeyer} = F_{res} * F_{scale} * F_{geo} * L$$

$$F_{res} = \frac{\gamma_p'}{\gamma_w} * (\eta * \tan\theta)$$

$$F_{scale} = \frac{d_{70m}}{\sqrt[3]{\kappa * L}} * \left(\frac{d_{70}}{d_{70m}}\right)^{0,4}$$

$$F_{geo} = 0,91 * \left(\frac{D}{L}\right)^{\frac{0,28}{\left(\frac{D}{L}\right)^{2,8} - 1} + 0,04}$$

$$\gamma_{mb} = \frac{H_{c,sellmeijer}}{\gamma_b * (\Delta H - fd * d)}$$

$$\gamma_{mb} = 1,20 \ (given\ in\ \text{“}Handreiking\ ontwerpen\ met\ overstromingskansen\text{"})$$

$$\gamma_b = 1,20 \ (estimated\ factor\ of\ \ schematization)$$

If these equation is solved than the seepage length L = 33,369 m. This seepage length is used in the four scenarios to determine the required factor of schematization. First all calculations for F_{pip} are made. By the results the calculation of the factor of schematization can be found. Here is de final factor of schematization determined.

Scenario 1: The ground level on the inside of the dike is 0,3 m lower

$Height\ of\ outlet = 12{,}1 - 0{,}3 = 11{,}8\ m\ + NAP$

$L = 33{,}369\ m$

$H_{c,sellmeijer} = 2{,}063$

$$\Delta H_c = \frac{1}{1{,}2} H_{c,sellmeijer} = \frac{2{,}063}{1{,}2} = 1{,}719$$

$$\Delta H_{optr} = H_{buiten} - H_{binnen} - 0{,}3d = 13{,}881 - 11{,}8 - 0{,}3 * 1{,}16 = 1{,}733$$

$$F_{pip} = \frac{\Delta H_c}{\Delta H_{optr}} = \frac{1{,}719}{1{,}733} = 0{,}992$$

Scenario 2: 1. The layer of clay is local 0,5m thinner

$d = 1{,}16 - 0{,}5 = 0{,}66\ m$

$L = 33{,}369\ m$

$H_{c,sellmeijer} = 2{,}063$

$$\Delta H_c = \frac{1}{1{,}2} H_{c,sellmeijer} = \frac{2{,}063}{1{,}2} = 1{,}719$$

$$\Delta H_{optr} = H_{buiten} - H_{binnen} - 0{,}3d = 13{,}881 - 12{,}1 - 0{,}3 * 0{,}66 = 1{,}583$$

$$F_{pip} = \frac{\Delta H_c}{\Delta H_{optr}} = \frac{1{,}719}{1{,}583} = 1{,}086$$

Scenario 3: The aquifer is 35 m thick instead of 21 m

$D = 35\ m$

$L = 33{,}369\ m$

$H_{c,sellmeijer} = 1{,}934$

$$\Delta H_c = \frac{1}{1{,}2} H_{c,sellmeijer} = \frac{1{,}934}{1{,}2} = 1{,}612$$

$$\Delta H_{optr} = H_{buiten} - H_{binnen} - 0{,}3d = 13{,}881 - 12{,}1 - 0{,}3 * 1{,}16 = 1{,}433$$

$$F_{pip} = \frac{\Delta H_c}{\Delta H_{optr}} = \frac{1{,}612}{1{,}433} = 1{,}125$$

Scenario 4: Locally the layer of clay is missing

$d = 0$

$L = 33{,}369\ m$

$H_{c,sellmeyer} = 2{,}063$

$$\Delta H_c = \frac{1}{1{,}2} H_{c,sellmeyer} = \frac{2{,}063}{1{,}2} = 1{,}719$$

$$\Delta H_{optr} = H_{buiten} - H_{binnen} - 0{,}3d = 13{,}881 - 12{,}1 - 0{,}3 * 0 = 1{,}781$$

$$F_{pip} = \frac{\Delta H_c}{\Delta H_{optr}} = \frac{1{,}719}{1{,}781} = 0{,}965$$

Results:

The results of the calculations for F_{pip} and the ΔF_{pip} are shown. For the determination of the factor of schematization the probability (P) is estimated. This is done in consultation with the engineers of Witteveen+Bos. The determination of the probabilities is based on their experience with this type of calculations. The probability can be 0,3%, 1%, 3%, 10% or 30%.

- The probability of the first scenario is estimated on 3%, there is very accurate data about the heights of the area around KEMA Laboratories. However it is possible that the ground is locally 0,3m lower. So a probability of 1% is too low and a percentage of 10% is too high.
- The probability of the second scenario is estimated on 3%. There are eight soil borings performed at the location of KEMA Laboratories. In all borings there is a layer of clay under the surface level from about 1,5m thick. It is possible that the layer of clay is locally 0,5m thinner. A probability of 1% is too low and a percentage of 10% is too high.
- The probability of the third scenario is estimated on 1%. For the estimation of the aquifer the deeper boring and the section of the soil is made. It's unlikely that the aquifer is that thick. However it is possible that there is a connection between the used aquifer and an underlying aquifer. The probability of 0,1% is too low, but 3% is too high. That is why 1% is chosen
- The probability of the fourth scenario is estimated on 1%. The eight soil borings that are performed at KEMA Laboratories show a layer of clay. However it is possible that the clay layer is missing because of for example an excavation on the foreland. This is not very like. The probability of 0,1% is too low, but 3% is too high. That is why 1% is chosen

Table 20: Results determining the factor of schematization

Scenario	F_{pip}	ΔF_{pip}	P	Factor of schematization
0	1,20	-	-	-
1	0,992	-0,17	3%	1,13
2	1,086	-0,09	3%	1,13
3	1,125	-0,06	1%	1,11
4	0,965	-0,195	1%	1,11

The required factor of schematization is 1,13. This factor is smaller than the first chosen factor of schematization, which means that this factor was big enough to cover the uncertainties about the surrounding. Met a factor of schematization of 1,13 is the seepage length calculated. With the formulas of Sellmeijer the seepage length is 31,01 = 31 m.

3. Calculations macro stability

Table with material factors

Grondsoort en parameter			Variatie-coëfficiënt V	γ_m
volumieke massa nat/droog		(ρ)		1,0
klei	(TP-CU-5%)			
	- cohesie	(c)	0,45	1,25
	- inwendige wrijving	(tan ϕ)	0,20	1,20
veen	(TP-CU-5%)			
	- cohesie	(c)	0,80	1,50
	- inwendige wrijving	(tan ϕ)	0,25	1,25
zand	(TP-CD)			
	- cohesie	(c)	n.v.t.	n.v.t.
	- inwendige wrijving	(tan ϕ)	0,15	1,20
samendrukkingsconstanten	- Terzaghi	(C, A)		1,1
	- Buisman-Koppejan	(Cp, Cs)		1,1

TP-CU-5% = triaxiaalproef, geconsolideerd en ongedraineerd, met 2 à 5% vervorming
TP-CD = triaxiaalproef, geconsolideerd en gedraineerd
Bij aantoonbaar lagere variatiecoëfficiënten voor cohesie en inwendige wrijving kunnen aangescherpte materiaalfactoren worden afgeleid. Bijvoorbeeld in het geval van natuurlijke niet-organische klei, waarvoor is aangetoond dat de variatiecoëfficiënten voor cohesie en inwendige wrijving kleiner of gelijk zijn aan respectievelijk $V_c \leq 0,275$ en $V_\phi \leq 0,15$, geldt $\gamma_{m,c} = 1,15$ en $\gamma_{m,\tan\phi} = 1,15$

Macro stability inner slope

Safety factor

For the calculations of the macro stability of the inner slope first the safety factor for macro stability is determined. This is done with the formula described in the Addendum Part A of the technical report “Technisch Rapport Waterkerende Grondconstructies”.

$$\gamma_S = 1 \text{ en } \gamma_R = \gamma_b\,\gamma_d\,\gamma_m\,\gamma_n \qquad (5.3.3)$$

γ_b partiële veiligheidsfactor die verband houdt met het schematiseren van de onder - grond (ook wel schematiseringsfactor genoemd)

γ_d partiële veiligheidsfactor die verband houdt met het gebruikte model (ook wel modelfactor genoemd)

γ_m partiële veiligheidsfactor die verband houdt met de materiaalparameters (ook wel materiaalfactor genoemd)

γ_n partiële veiligheidsfactor die verband houdt met schade (ook wel schadefactor genoemd)

γ_R veiligheidsfactor van de sterkte

γ_S veiligheidsfactor van de belasting

Figure 37: Formula for the safety factor of the macro stability

Macro stability is calculated following the Mohr-Coulomb model with the method of Bishop. The method that is prescribed in the “Handreiking Ontwerpen met Overstromingskansen” is the CSSM method. For this method is more information needed about the soil (like the stress and strain of the soil), since this data is not available about the soil the Mohr-Coulomb method is used. For the calculation of the safety factor for macro stability the partial safety factor are given in “Handreiking ontwerpen met overstromingskansen”.

$\gamma_R = \gamma_b * \gamma_d * \gamma_m * \gamma_n$

$\gamma_b = 1{,}10$, the factor of schematization for macro stability is normally calculated similar to the way the factor of schematization for piping is determined. Due to limited time for the research is in consultation with engineers from Witteveen+Bos this factor of schematization estimated on 1,10. Witteveen+Bos has many experience with the determination of factor of schematizations. In further research this factor of schematization can be calculated.

$\gamma_d = 1{,}0$, the model factor is 1,0. Uplifting does not apply for this calculation so the model. For the calculations of macro stability another soil structure is chosen. This soil structure is not sensitive for the failure mechanism for piping. (Ministry of Infrastructure and the Environment, 2015)

$\gamma_m = 1{,}0$, the material factor is 1,0 because the material factors are already used in the design values of the soil in the calculations.

$\gamma_n = 1{,}06$, depends on the requirement for the strength. This factor is deduced from Annex A from “Handreiking ontwerpen met Overstromingskansen” (Ministry of Infrastructure and the Environment, 2015).

The required safety factor for macro stability is: $\gamma_R = 1{,}10 * 1{,}0 * 1{,}0 * 1{,}06 = 1{,}17$

All dike designs have to satisfy this safety factor (or have a higher safety factor) to satisfy on macro stability.

Phreatic lines

After the determination of the safety factor the phreatic lines in the dike are schematized. For every dike design there are two phreatic lines: 1. The phreatic line drawn according to the technical report “Technisch Rapport Waterspanningen bij Dijken” (Technische Adviescommissie voor de Waterkeringen, 2004) and 2. the phreatic line on the design water level of 13,881m +NAP.

Load on the dike

For the load of the maintenance vehicles a temporary load of 5 kN/m^2 is added to the designs. The load has a width of 2,5 meters and is located on top of the dike 1,5m of the boundary of the inner slope. The distribution of the load is set on 30°. For the soils of the soil structure is the degree of consolidation for clay set on 0% and for sand on 100%. The used values are determined in consultation with the engineers of Witteveen+Bos and the technical report “Technisch Rapport Waterkerende Grondconstructies” (Technische Adviescommissie voor de Waterkering, 2001).

Results calculations

The macro stability of the inner slope has to satisfy the safety factor of 1,17.

Table 21: Results D-Geostability of macro stability of the inner slope

Nr	Location	Place	Material	Calculated safety factor	Satisfies safety factor of 1,17?
1	West	Partly on terrain	Clay	1,69	Yes
2	West	Partly on terrain	Sand	1,73	Yes
3	West	Foreland	Clay	1,07	No
4	West	Foreland	Sand	1,20	Yes
5	South	Foreland	Clay	1,24	Yes
6	South	Foreland	Sand	1,26	Yes
7	South	Terrain	Clay	1,92	Yes
8	South	Terrain	Sand	1,98	Yes

Design optimization

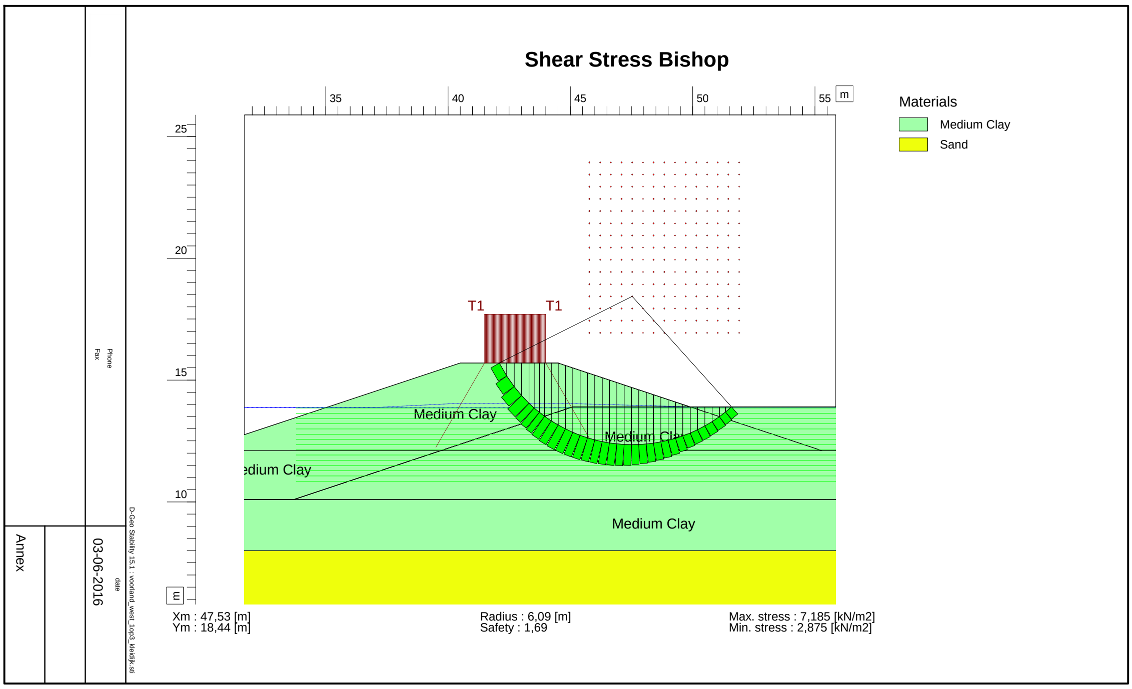
The design on location west on the foreland made with clay does not satisfy the safety factor. For the designs calculations it is assumed that the clay in the ground is clean clay with an angle internal friction of 17,5°. If the clay at this location is a more sandy clay, then the angle of internal friction is 22,5°. If the macro stability of the inner slope for this design is calculated with the characteristic value of 22,5° and a design value of 19° then the calculated safety factor is 1,24 and then the design does satisfy the safety factor. The soil at the location and for the dike has to be tested to show that it satisfies this characteristic.

Only the results of the calculations that satisfy the safety factor are presented.

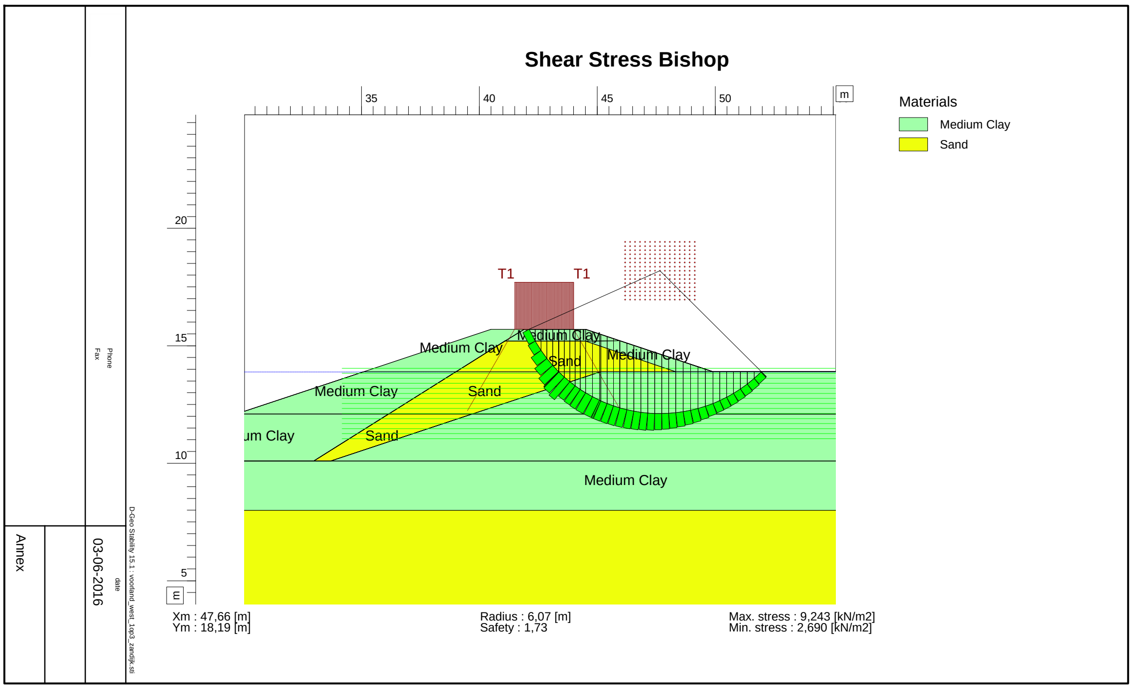
Results simulations

Location West

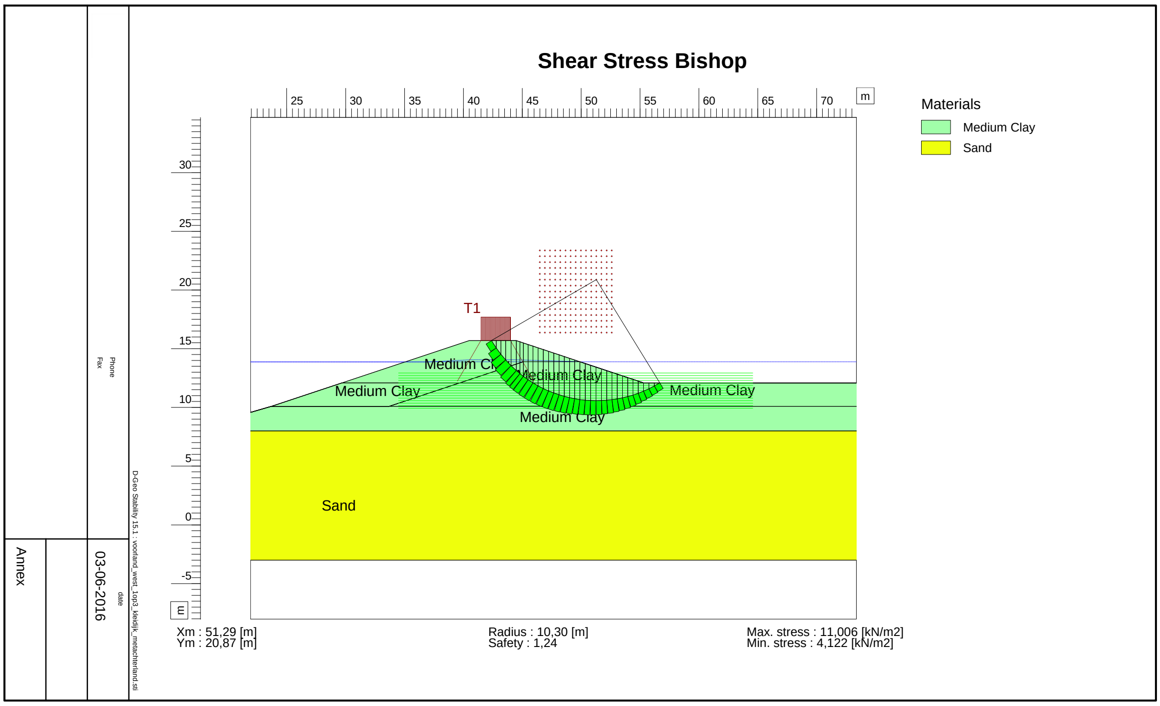
- West: Clay dike partly on terrain of KEMA Laboratories



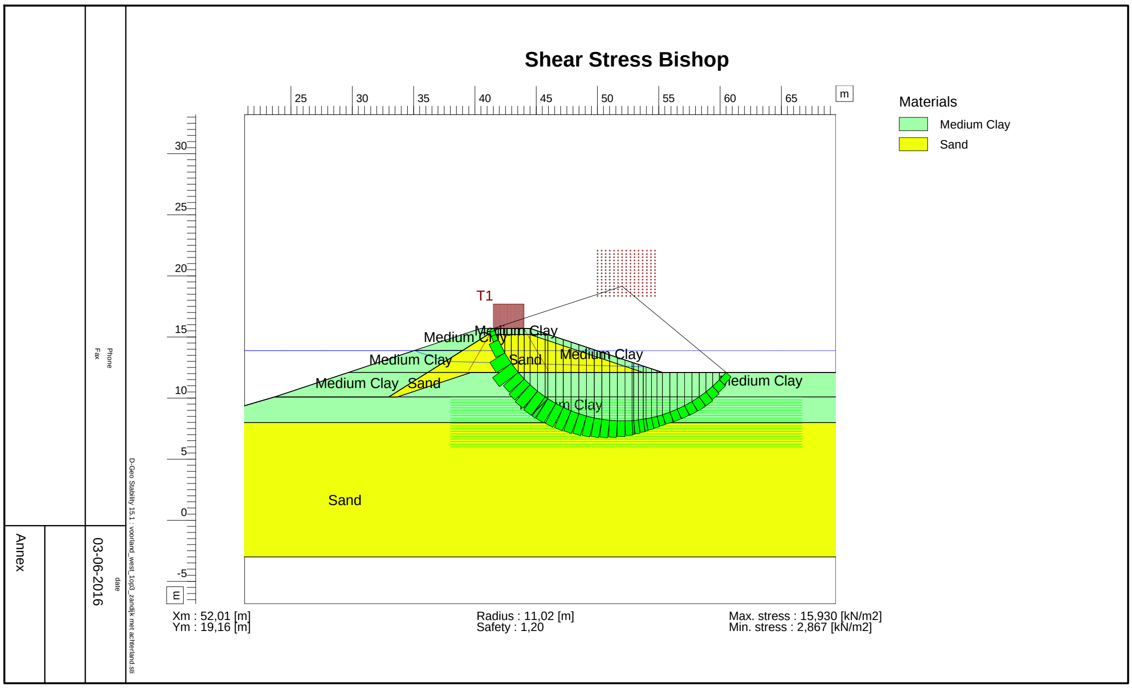
- West: Sand dike partly on terrain of KEMA Laboratories



➢ West: Clay dike on foreland

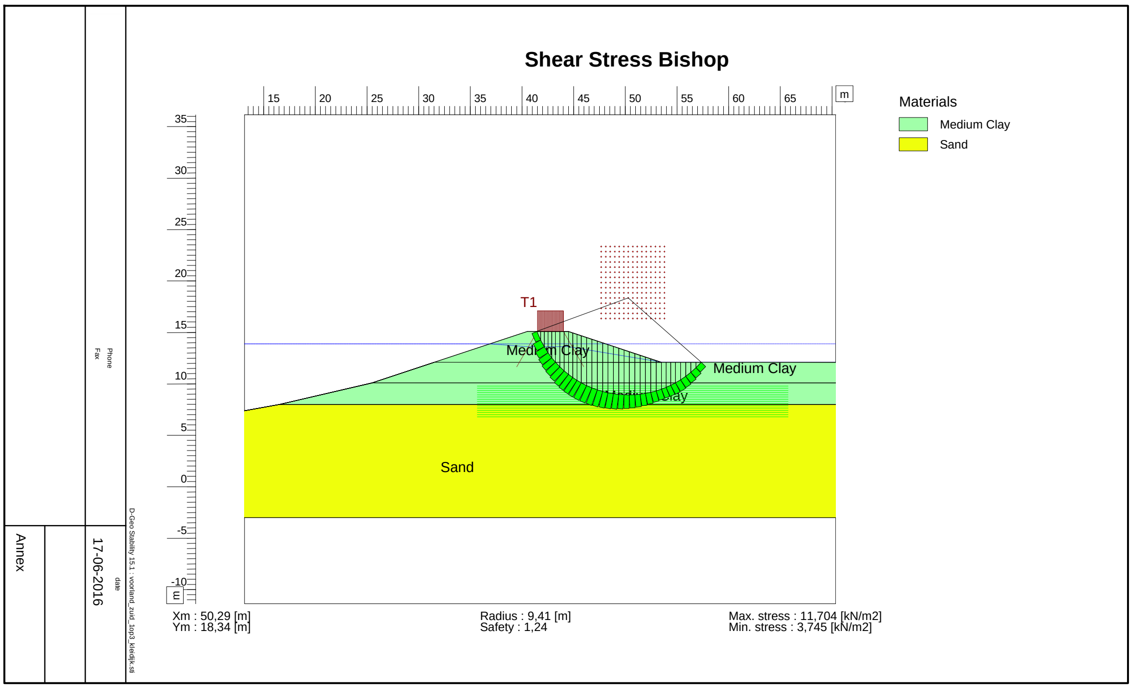


➢ West: Sand dike on foreland

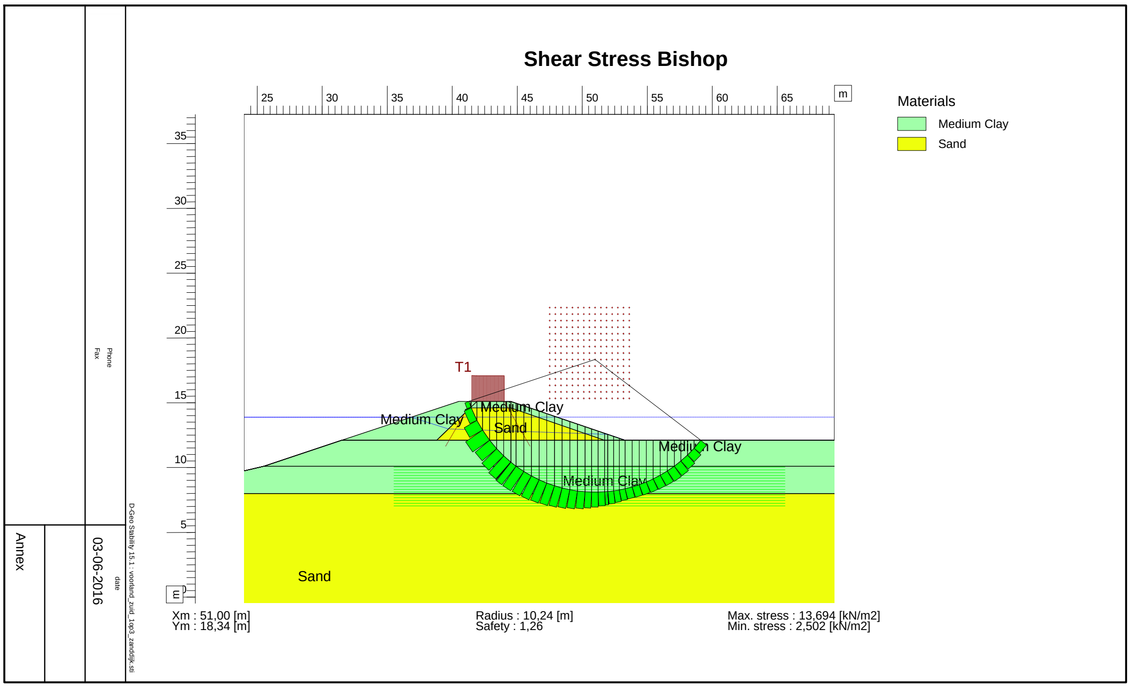


Location South

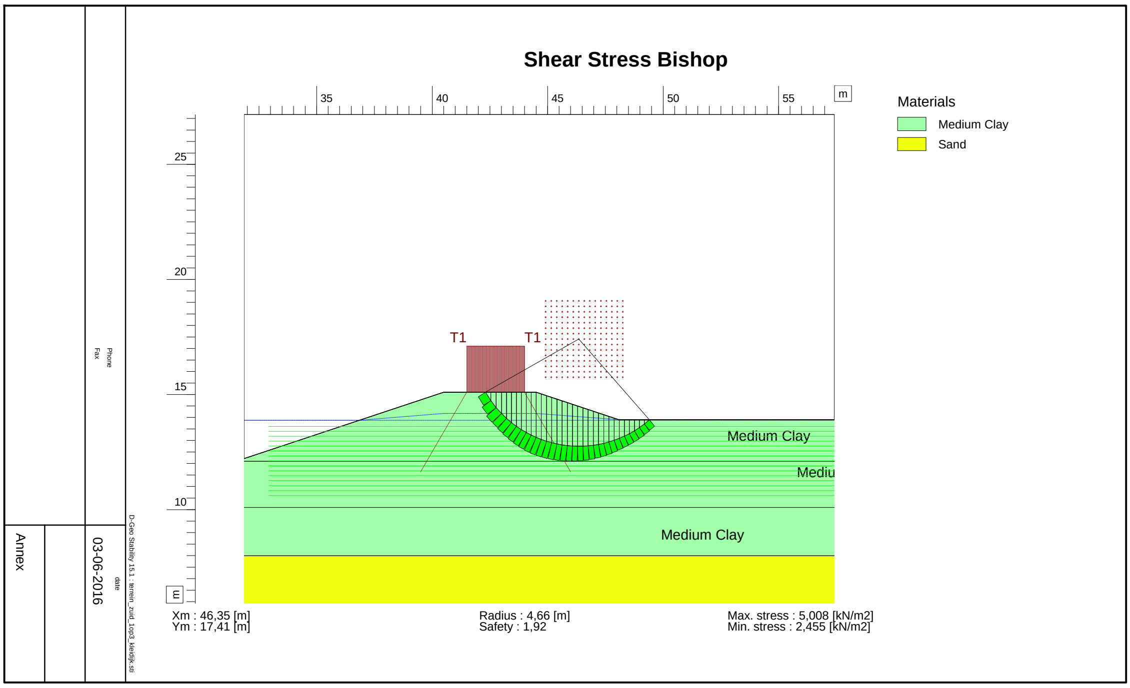
- South: Clay dike on foreland



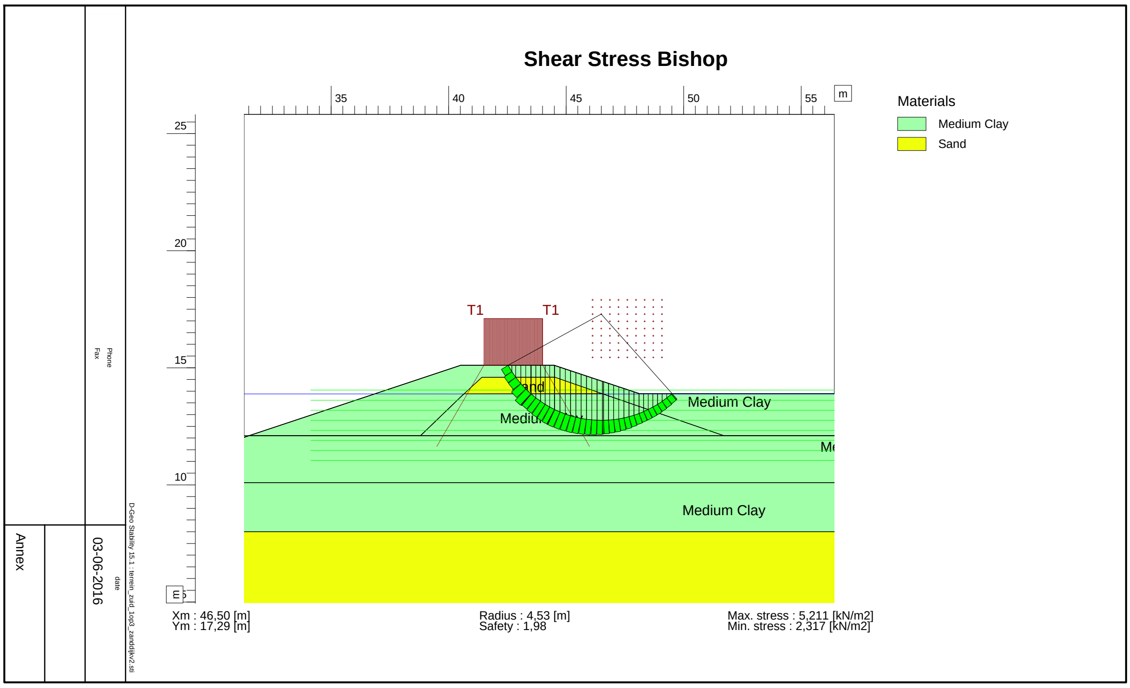
- South: Sand dike on foreland



- South: Clay dike on terrain of KEMA Laboratories



- South: Sand dike on terrain of KEMA Laboratories



Calculations macro stability outer slope

After that the macro stability of the inner slope is determined, the macro stability of the outer slope is calculated.

Safety factor

First the safety factor for the macro stability of the outer slope is determined. The safety factor of the outer slope can be determined with the same method how the safety factor of the inner slope is determined. So the same formula will be used for the determination of the safety factor of piping. Failing of the dike because of the macro stability of the outer slope only happens when the outer water level drops. This means that the fail probability on the section level can be divided by the probability of a flood due to the loss of macro stability of the outer slope. In “Handreiking ontwerpen met overstromingskansen” it is advised to use the probability of 0,1. The safety factor for macro stability of the outer slope is determined with this new probability on 1,06. This safety factor is calculated in consultation with the engineers of Witteveen+Bos.

Phreatic lines

For the calculations for the macro stability of the outer slope it is assumed that the dike is fully saturated. The phreatic lines inside the dike stay the same as for the calculations of the macro stability of the inner slope. The phreatic lines drop 30cm under the ground level of the outer slope. The top layer of the dike is not capable of holding the water due to the grass revetment on the dike. It is assumed that there is no water in this part of the dike. The second phreatic line drops to the water level of 11,35. This water level is the yearly high water level. This value is chosen as a conservative assumption. A higher water level has a negative effect on the outer macro stability. This value is also chosen because it is not logical that the water level in the Lower Rhine immediately drops to the normal water level after a period of high water.

Load on the dike

The load on the dike is the same as for the calculations for the macro stability of the inner slope.

Results

The results of the simulations can be found on the next page. Only the results that satisfy the safety factor are presented. The designs should satisfy the safety factor of 1,06 for the macro stability of the outer slope. The results of the calculated safety factors for the dike designs are shown in Table 22.

Table 22: Results D-Geostability of macro stability of the outer slope

Nr	Location	Place	Material	Calculated safety factor	Satisfies safety factor of 1,06?
1	West	Partly on terrain	Clay	0,95	No
2	West	Partly on terrain	Sand	0,96	No
3	West	Foreland	Clay	0,95	No
4	West	Foreland	Sand	1,04	No
5	South	Foreland	Clay	1,00	No
6	South	Foreland	Sand	1,04	No
7	South	Terrain	Clay	1,16	Yes
8	South	Terrain	Sand	1,16	Yes

Design optimization

The majority of the design does not satisfy the calculated safety factor of 1,06. The safety factors of the designs are all calculated with the soil characteristics for clean clay, which has an angle of internal friction of 17,5° (characteristic value). If the used soil for the dike and the ground satisfies a value for the angle of internal friction of 22,5° (characteristic value) and so a design value of 19°. For the dike designs it has to be researched if the used clay satisfies this angle of internal friction. Alternative solutions for the macro instability are a lower slope or an outer berm; however these solutions require more space and soil and this is more expensive. The results of the calculations with a design value of 19° for the angle of internal friction for clay are shown in Table 12.

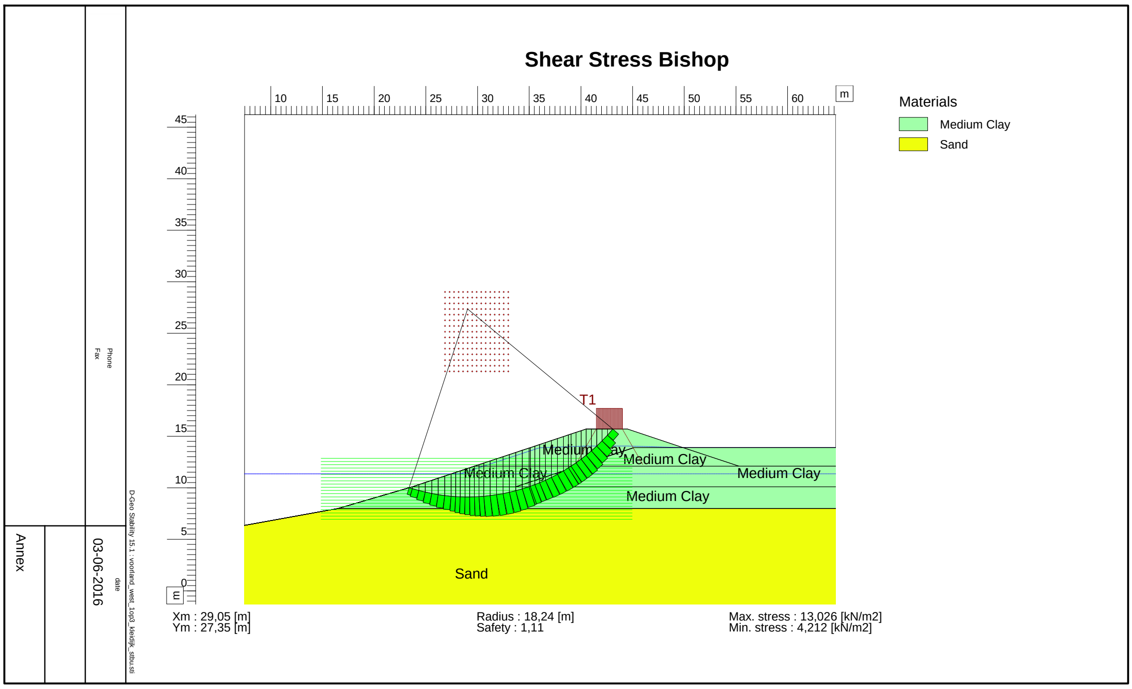
Table 23: Results D-Geostability of macro stability with stronger clay

Nr	Location	Place	Material	Calculated safety factor	Satisfies safety factor of 1,06?
1	West	Partly on terrain	Clay	1,11	Yes
2	West	Partly on terrain	Sand	1,11	Yes
3	West	Foreland	Clay	1,11	Yes
4	West	Foreland	Sand	1,18	Yes
5	South	Foreland	Clay	1,16	Yes
6	South	Foreland	Sand	1,20	Yes
7	South	Terrain	Clay	1,16	Yes
8	South	Terrain	Sand	1,16	Yes

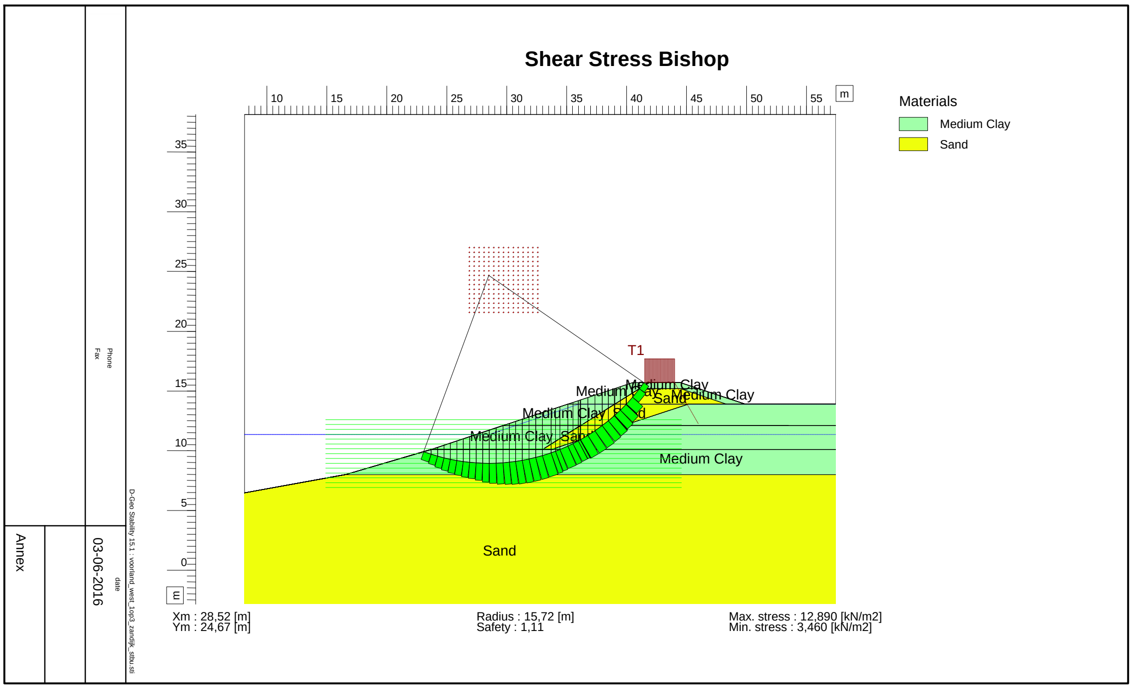
Results simulations

Location West

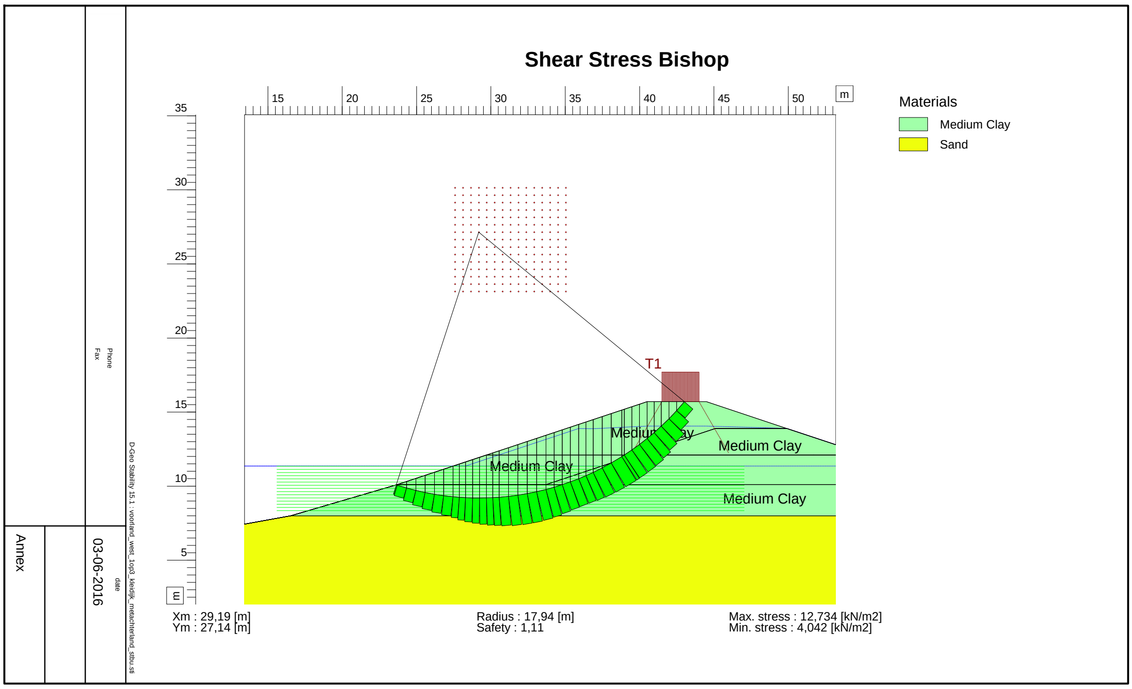
➢ West: Clay dike partly on terrain of KEMA Laboratories



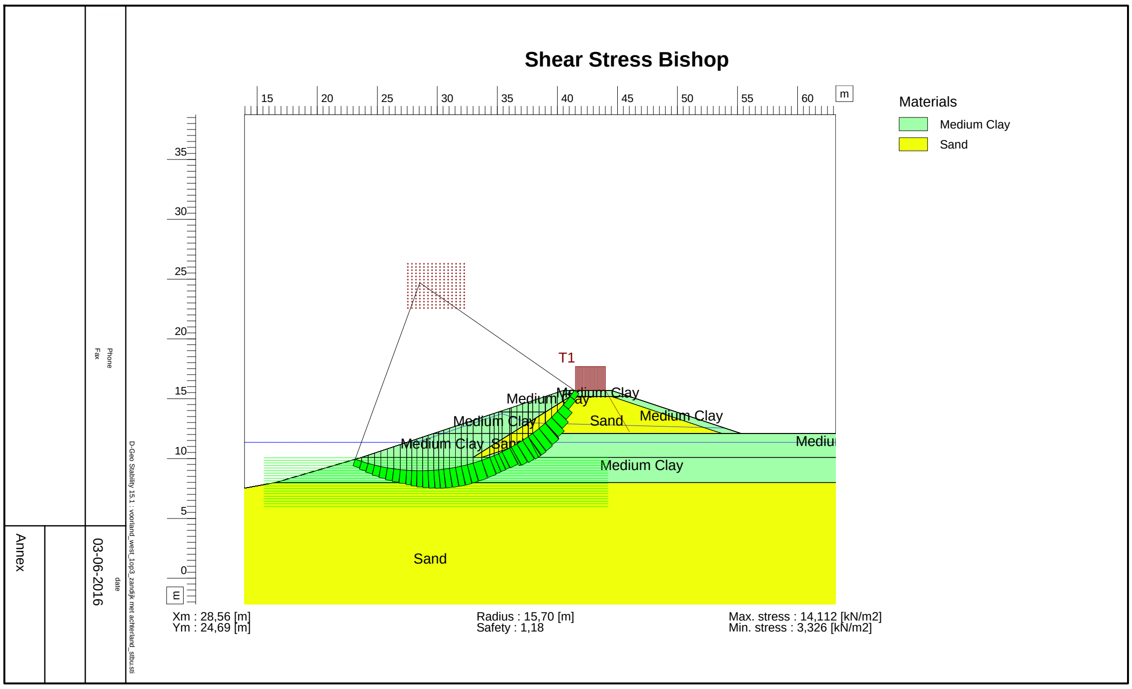
➢ West: Sand dike partly on terrain of KEMA Laboratories



➢ West: Clay dike on the foreland

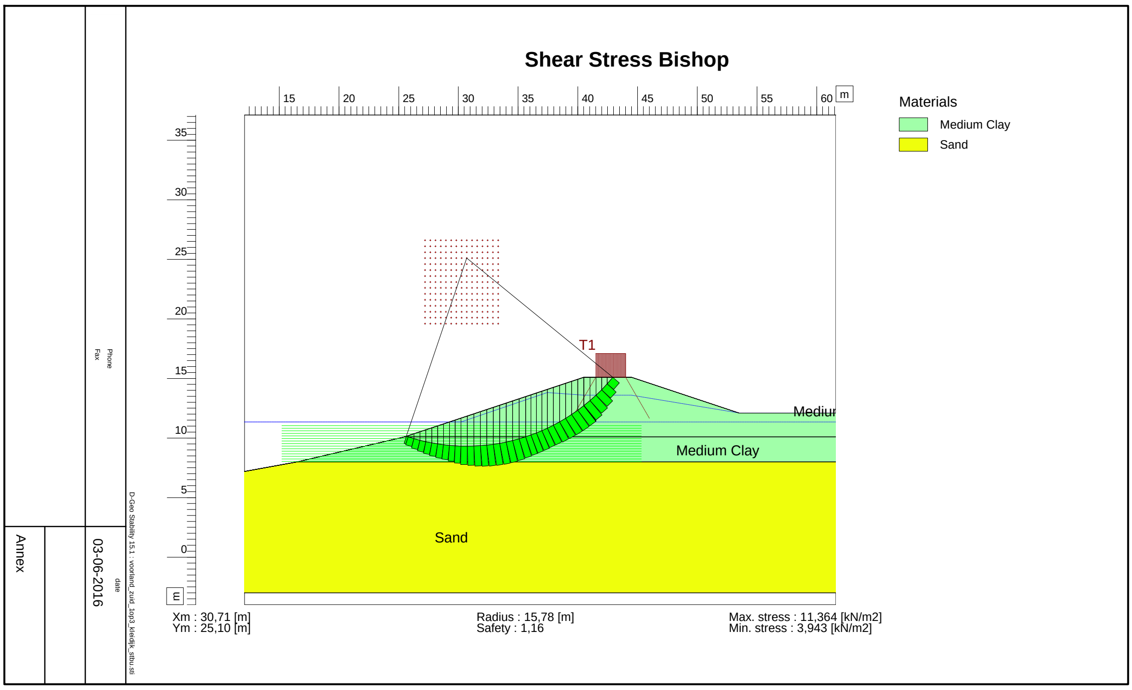


➢ West: Sand dike on foreland

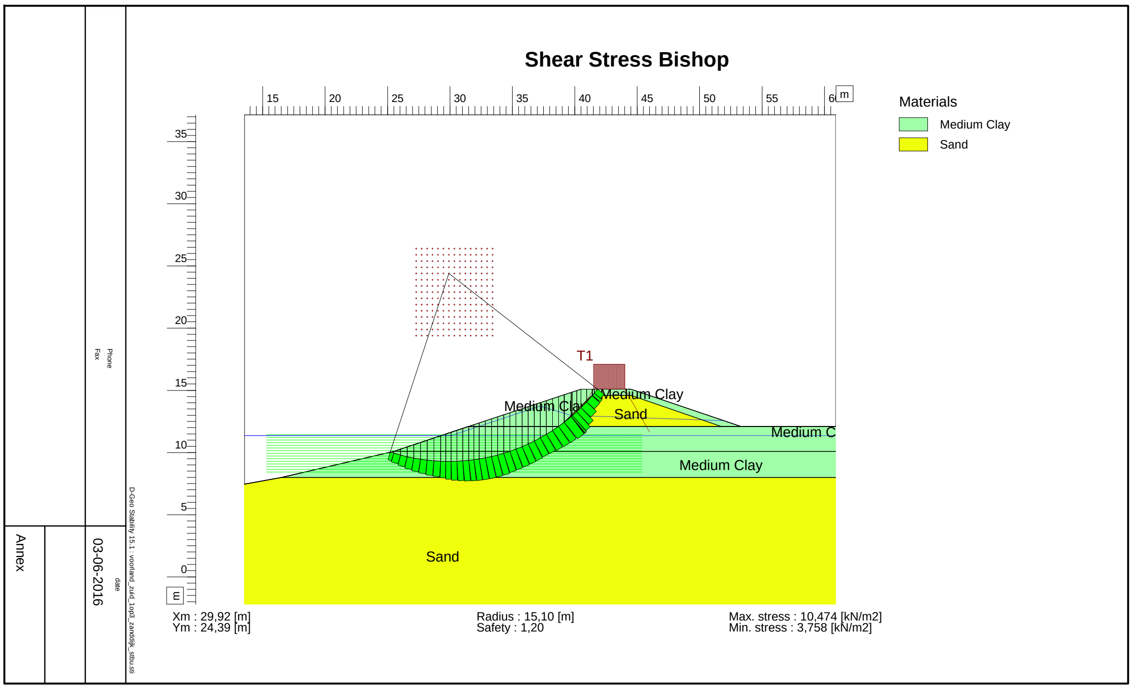


Location South

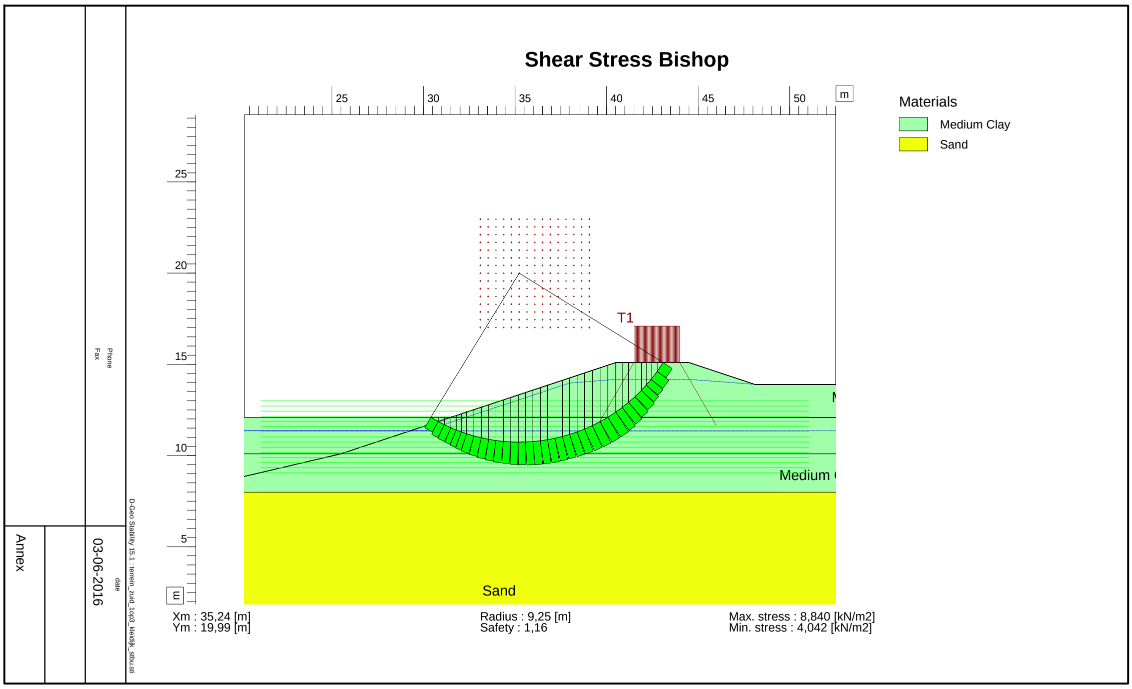
- South: clay dike on foreland



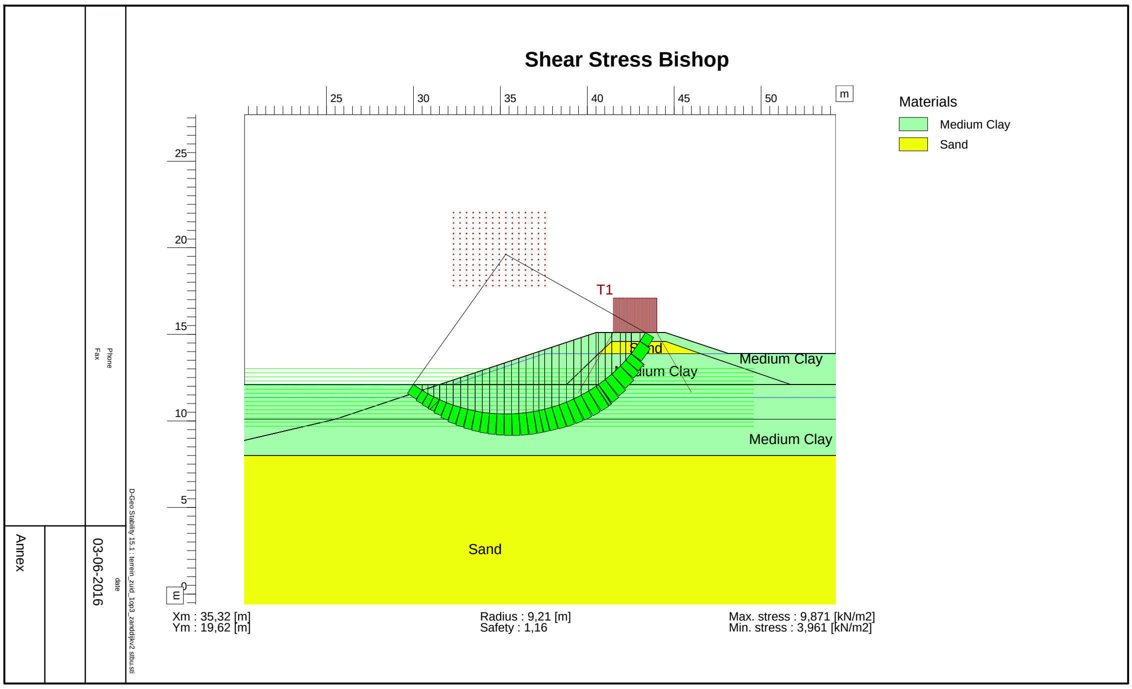
- South: Sand dike on foreland



➤ South: Clay dike on terrain of KEMA Laboratories



➤ South: Sand dike on terrain of KEMA Laboratories



E. Cost calculation

1. Determining required quantities

For the cost calculation first the surface area of the materials are determined from the dike sections of the dike options. There after the surface areas are multiplied by the length of the dike. The lengths of the dike paths are determined with the measuring tool in QGis. This method is shown in Figure 38 and Figure 39.

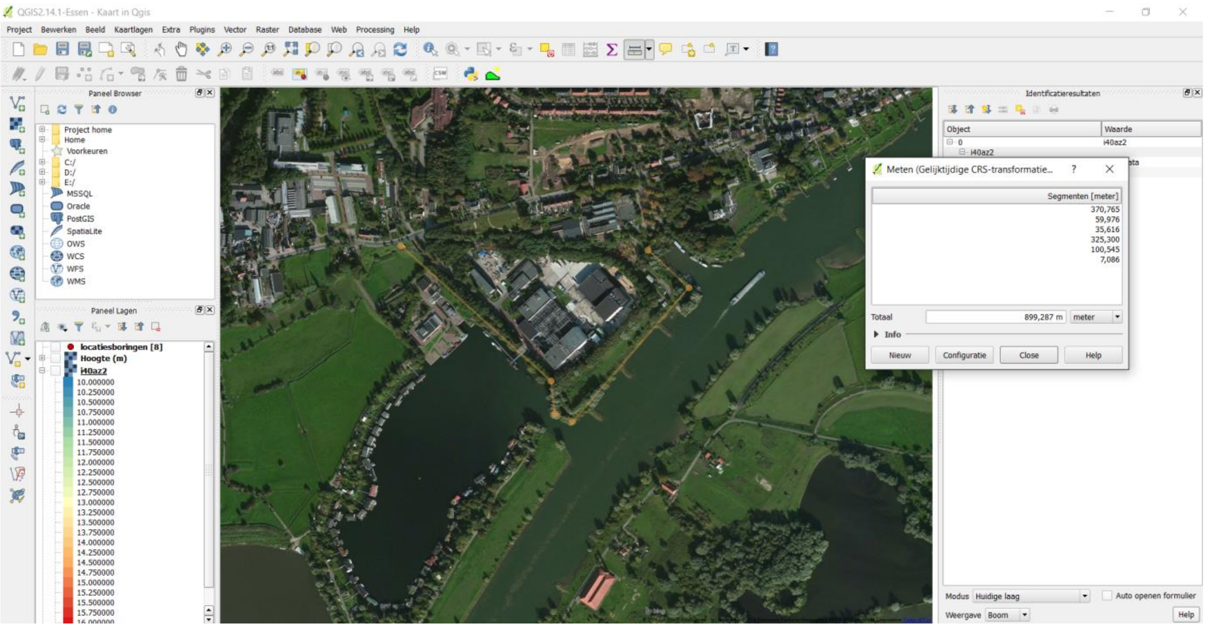


Figure 38: Determining lengths dike path dike on foreland

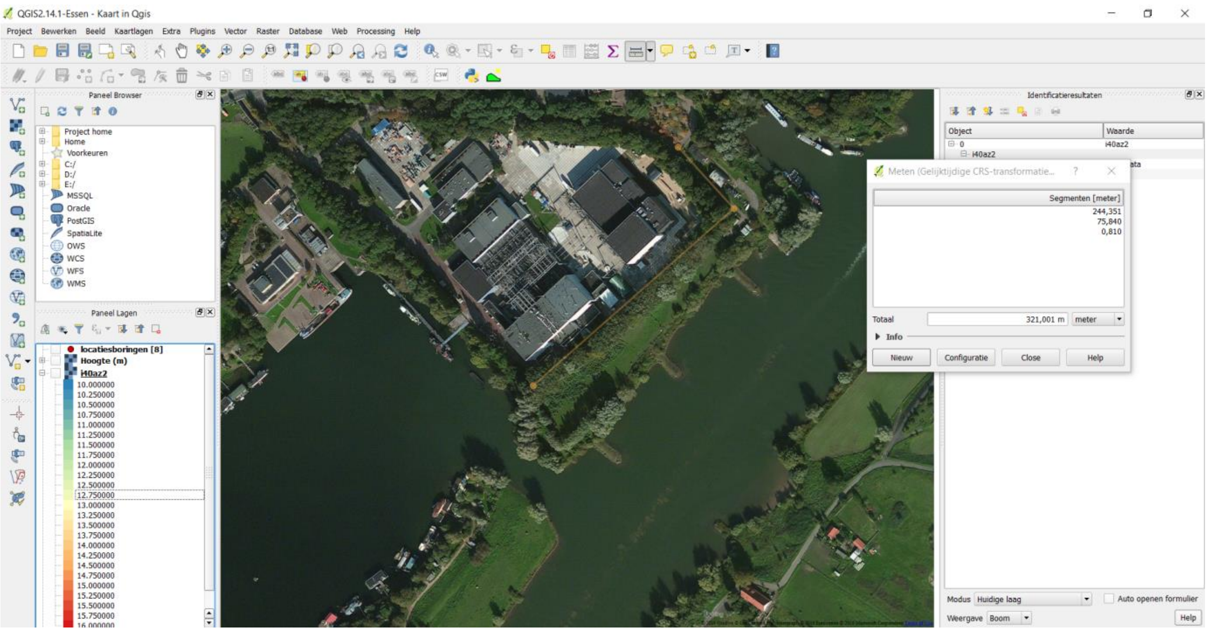


Figure 39: Determining lengths dike paths for dike on terrain of KEMA Laboratories

The results are shown in Figure 40. These lengths are used for the determination of the costs.

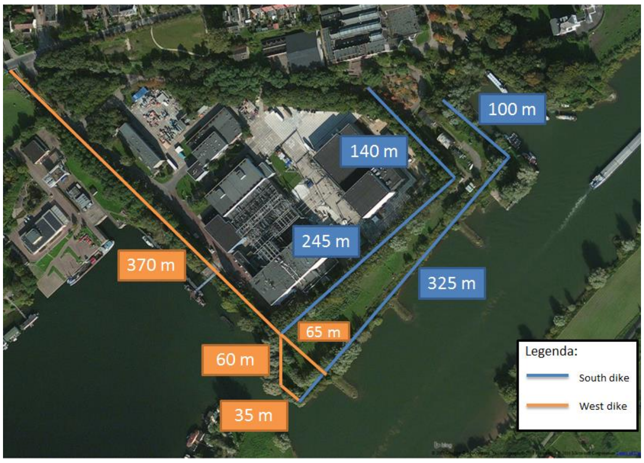


Figure 40: Length of the dike paths

The surface areas of the dike are determined as follows. From the sections of the dike that are used in the calculations of the macro stability the surface areas are determined. This surface area is then multiplied by the length of the dike path. The required material is then determined. With the quantities of the needed soil is thereafter the total cost of the individual dike determined.

There are two types of dike: a clay dike and a sand dike. The clay dike consists of two types of clay: a normal type of clay for the core and a better type of clay (cat.2) for the top layer. The sand dike consists of a sand core with a clay top layer. On the clay top layer a grass revetment will be placed. This grass will be of the sort 100-150 kg/ha.

For the dike design on the foreland on KEMA Laboratories there will be:

- 370 m of the west dike partly on terrain of KEMA Laboratories
- 60+35= 95m dike from the west dike on the foreland
- 325+100 = 425m from the south dike on the foreland

For the dike design on the foreland of KEMA Laboratories there will be:

- 370 m of the west dike partly on terrain of KEMA Laboratories
- 245+140=385m of the south dike on the terrain of KEMA Laboratories

This requires the following amounts of soil:

1. West: clay dike partly on terrain of KEMA Laboratories

Material	Quantity	Meters dike	Required soil
Clay cat. 2	33,6 m^2	370	12432 m^3
Clay normal	21,3 m^2	370	7881 m^3
Sand	-	370	-
Grass	27,4 m	370	10138 m^2

2. West: Sand dike partly on terrain of KEMA Laboratories

Material	Quantity	Meters dike	Required soil
Clay cat. 2	33,6 m^2	370	12432 m^3
Clay normal	-	370	-
Sand	21,3 m^2	370	7881 m^3
Grass	27,4 m	370	10138 m^2

3. West: Clay dike on the foreland

Material	Quantity	Meters dike	Required soil
Clay cat. 2	16,5 m2	95	1568 m^3
Clay normal	36,8 m2	95	3496 m^3
Sand	-	95	-
Grass	33,1 m	95	3145 m^2

4. West: Sand dike on the foreland

Material	Quantity	Meters dike	Required soil
Clay cat. 2	16,5 m2	95	1568 m^3
Clay normal	-	95	-
Sand	36,8 m2	95	3496 m^3
Grass	33,1 m	95	3145 m^2

5. South: clay dike on the foreland

Material	Quantity	Meters dike	Required soil
Clay cat. 2	23,35 m^2	425	9924 m^3
Clay normal	20,05 m^2	425	8521 m^3
Sand	-	425	-
Grass	29,3	425	12453 m^2

6. South: Sand dike on the foreland

Material	Quantity	Meters dike	Required soil
Clay cat. 2	23,35 m^2	425	9924 m^3
Clay normal	-	425	-
Sand	20,05 m^2	425	8521 m^3
Grass	29,3 m	425	12453 m^2

7. South: Clay dike on terrain of KEMA Laboratories

Material	Quantity	Meters dike	Required soil
Clay cat. 2	5,87 m^2	385	2260 m^3
Clay normal	3,25 m^2	385	1251 m^3
Sand	-	385	-
Grass	11,7 m	385	4505 m^2

8. South: Sand dike on terrain of KEMA Laboratories

Material	Quantity	Meters dike	Required soil
Clay cat. 2	5,87 m2	385	2260 m^3
Clay normal	-	385	-
Sand	3,25 m2	385	1251 m^3
Grass	11,7 m	385	4505 m^2

With the department for cost evaluation of Witteveen+Bos the cost for the different dike designs are determined. The costs of the 10 different dike designs are then used to calculate the costs of the three options. The costs of the individual dike can be found in Table 24.

Table 24: Cost calculation of individual dike designs

Dike design	Material	Length of dike path [m]	Calculated costs [€]
1. West- foreland partly on terrain of KEMA	Clay	370	718.998
2. West – foreland partly on terrain of KEMA	Sand	370	622.375
3. West – foreland	Clay	95	173.236
4. West – foreland	Sand	95	130.374
5. South – foreland	Clay	425	648.768
6. South – foreland	Sand	425	544.557
7. South – terrain	Clay	385	126.296
8. South – terrain	Sand	385	110.955
9. West – foreland – short dike	Clay	65	21.323
10. West- foreland – short dike	Sand	65	18.733

With the cost of the individual dikes the cost of the options for the dike can be calculated. The costs of the 6 dike options are shown in Table 25.

Table 25: Cost calculation of dike options

Option	Used dike designs	Cost[€]
Design 1: Clay dike all around the foreland	1, 3, 5	1.541.002
Design 2: Sand dike all around the foreland	2, 4, 6	1.297.306
Design 3: Clay dike with room outside the dike	1, 5, 9	1.389.089
Design 4: Sand dike with room outside the dike	2, 6, 10	1.185.665
Design 5: Clay dike on terrain of KEMA Laboratories	1, 7	845.294
Design 6: Sand dike on terrain of KEMA Laboratories	2, 8	733.330

2. Cost evaluation made by Witteveen+Bos

The cost evaluation that has been made for the individual dikes can be found on the next page. For the following dikes the costs are determined:

1. Location west- Clay dike partly on the terrain of KEMA Laboratories
2. Location west – Sand dike partly on the terrain of KEMA Laboratories
3. Location west – Clay dike on the foreland
4. Location west – Sand dike on the foreland
5. Location south – Clay dike on the foreland
6. Location south – Sand dike on the foreland
7. Location south – Clay dike on the terrain of KEMA Laboratories
8. Location south – Sand dike on the terrain of KEMA Laboratories
9. Location west – Short clay dike on foreland
10. Location west – Short sand dike on foreland

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
	Colofon	Status:	Ongecontr.	Auteur:	0

PROJECT — **BACHELOR OPDRACHT ELLEN DAAMEN**

PROJECTFASE — **INITIATIEFFASE**

Scopebeschrijving en/of uitgangspunten

Uitgegaan van:

- Deterministische raming van **bouwkosten** (§ 7.1 lid 2.4 en 2.5)
- Geschatte bandbreedte +/- 40%
- Bedrijfseconomische raming (§ 7.1 lid 1.7)
- Hoeveelhedenboek met 10 onderdelen (de objecten)

Varianten

Dit betreft een raming ter vergelijking van varianten. Kostentechnische verschillen van (onderdelen van) varianten worden met deze ramingen inzichtelijk gemaakt. Deze vergelijking is nadrukkelijk niet geschikt voor een budgetaanvraag.

- Varianten nader samen te stellen uit de (te combineren) objecten 1 t/m 10

Risico's

- In de objecten is rekening gehouden met objectgebonden risico's, het betreft een voorziening voor met name technische risico's.
- Er is geen rekening gehouden met projectgebonden risico's, het betreft hier met name overige risico's zoals juridische, organisatorische, maatschappelijke, ruimtelijke en financiele risico's.

Niet inbegrepen zijn kosten voor:

Bouwkosten

- Bodemvreemde materialen / NGE / archeologie
- Asbest, bodem en grondwatersanering

Engineeringkosten

- Engineeringskosten aannemer(s)
- Engineeringskosten adviesbureau(s)
- Engineeringskosten opdrachtgever
- Onderzoekskosten

Levensduurkosten (§ 7.1 lid 2.1)

- Beheer en onderhoud
- (grote) vervangingen
- Exploitatiekosten
- Sloopkosten (einde levensduur)
- Rentekosten

Vastgoedkosten

- Grondverwerving
- Planschade
- Nadeelcompensatie

Overige bijkomende kosten

- Landschappelijke inpassingen
- Mitigerende maatregelen
- Kabels en leidingen
- Leges en heffingen
- Vergunningen
- Verzekeringen

Overige (scope) uitsluitingen

- Objectoverstijgende risico's
- Onzekerheidsreserve
- Reservering scopewijzigingen
- BTW

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
	Projectsamenvatting	Status:	Ongecontr.	Auteur:	0

code post	omschrijving post	Directe kosten Benoemd	Directe kosten Nader te detailleren	Indirecte kosten	Voorziene kosten	Risico-reservering	Totaal
	INVESTERINGSKOSTEN (Indeling naar categorie)						
BK01	Bouwkosten Locatie west: Voorland klei	€ 439.838	€ 65.976	€ 119.402	€ 625.215	€ 93.782	€ 718.998
BK02	Bouwkosten Locatie west: Voorland zand	€ 380.730	€ 57.110	€ 103.356	€ 541.196	€ 81.179	€ 622.375
BK03	Bouwkosten Locatie west: voorland klei met achterland	€ 105.975	€ 15.896	€ 28.769	€ 150.640	€ 22.596	€ 173.236
BK04	Bouwkosten Locatie west: voorland zand met achterland	€ 105.975	€ 15.896	€ 28.769	€ 150.640	€ 22.596	€ 173.236
BK05	Bouwkosten Locatie zuid: Voorland klei	€ 396.876	€ 59.531	€ 107.739	€ 564.146	€ 84.622	€ 648.768
BK06	Bouwkosten Locatie zuid: Voorland zand	€ 333.126	€ 49.969	€ 90.433	€ 473.528	€ 71.029	€ 544.557
BK07	Bouwkosten Locatie zuid: Terrein klei	€ 77.260	€ 11.589	€ 20.974	€ 109.823	€ 16.473	€ 126.296
BK08	Bouwkosten Locatie zuid: Terrein zand	€ 77.260	€ 11.589	€ 20.974	€ 109.823	€ 16.473	€ 126.296
BK09	Bouwkosten Locatie west: Tussendijk klei	€ 13.044	€ 1.957	€ 3.541	€ 18.541	€ 2.781	€ 21.323
BK10	Bouwkosten Locatie west: Tussendijk zand	€ 11.460	€ 1.719	€ 3.111	€ 16.289	€ 2.443	€ 18.733
	Variatiecoëfficiënt (geschat)					*40%*	
	Risico's in relatie tot de voorziene kosten					*15%*	

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
(Deel)raming:	Locatie west: Voorland klei	Status:	Ongecont	Auteur:	0

code post	omschrijving post	hoeveelheid	eenheid		prijs		totaal
1							
	INVESTERINGSKOSTEN	370	m				
20	**Grondwerk**						
200120	Klei leveren en verwerken in kern	7.881,00	m3	€	20,00	€	157.620,00
200130	Klei leveren en verwerken in afdekking (categorie 2), dik 0,5-2,3 m	12.432,00	m3	€	22,50	€	279.720,00
	Totaal grondwerk			**€**	**437.340,00**		
30	**Gras**						
300110	Profileren en inzaaien gras	99,90	are	€	25,00	€	2.497,50
	Totaal gras			**€**	**2.497,50**		
	Benoemde directe bouwkosten					**€**	**439.838**
NTD011	Nader te detailleren bouwkosten	15,0%		€	439.838	€	65.976
	Directe bouwkosten					**€**	**505.813**
IK016	Eenmalige kosten	2,0%		€	505.813	€	10.116
IK017	Algemene bouwplaatskosten	1,0%		€	505.813	€	5.058
IK019	Uitvoeringskosten	6,0%		€	505.813	€	30.349
IK0110	Algemene kosten	8,0%		€	551.336	€	44.107
IK0111	Winst	3,0%		€	595.443	€	17.863
IK0112	Risico	2,0%		€	595.443	€	11.909
	Indirecte bouwkosten	24%				**€**	**119.402**
VZBK	**Voorziene bouwkosten**					**€**	**625.215**
RBK013	Niet benoemd objectrisico bouwkosten	15,0%		€	625.215	€	93.782
RBK	**Risico's bouwkosten**	15%				**€**	**93.782**
BK01	**Bouwkosten Locatie west: Voorland klei**					**€**	**718.998**

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
(Deel)raming:	Locatie west: Voorland zand	Status:	Ongecont	Auteur:	0

code post	omschrijving post	hoeveelheid	eenheid		prijs		totaal
2							
	INVESTERINGSKOSTEN	370	m				
20	**Grondwerk**						
200210	Zand leveren en verwerken in kern	7.881,00	m3	€	12,50	€	98.512,50
200230	Klei leveren en verwerken in afdekking (categorie 2), dik 0,5-2,3 m	12.432,00	m3	€	22,50	€	279.720,00
	Totaal grondwerk			**€**	**378.232,50**		
30	**Gras**						
300210	Profileren en inzaaien gras	99,90	are	€	25,00	€	2.497,50
	Totaal gras			**€**	**2.497,50**		
	Benoemde directe bouwkosten					**€**	**380.730**
NTD021	Nader te detailleren bouwkosten	15,0%		€	380.730	€	57.110
	Directe bouwkosten					**€**	**437.840**
IK026	Eenmalige kosten	2,0%		€	437.840	€	8.757
IK027	Algemene bouwplaatskosten	1,0%		€	437.840	€	4.378
IK029	Uitvoeringskosten	6,0%		€	437.840	€	26.270
IK0210	Algemene kosten	8,0%		€	477.245	€	38.180
IK0211	Winst	3,0%		€	515.425	€	15.463
IK0212	Risico	2,0%		€	515.425	€	10.308
	Indirecte bouwkosten	24%				**€**	**103.356**
VZBK	**Voorziene bouwkosten**					**€**	**541.196**
RBK023	Niet benoemd objectrisico bouwkosten	15,0%		€	541.196	€	81.179
RBK	**Risico's bouwkosten**	15%				**€**	**81.179**
BK02	**Bouwkosten Locatie west: Voorland zand**					**€**	**622.375**

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
(Deel)raming:	Locatie west: voorland klei met achterland	Status:	Ongecont	Auteur:	0

code post	omschrijving post	hoeveelheid	eenheid		prijs		totaal
3							
	INVESTERINGSKOSTEN	95	m				
20	**Grondwerk**						
200320	Klei leveren en verwerken in kern	3.496,00	m3	€	20,00	€	69.920,00
200330	Klei leveren en verwerken in afdekking (categorie 2), dik 0,5-2,3 m	1.567,50	m3	€	22,50	€	35.268,75
	Totaal grondwerk			**€**	**105.188,75**		
30	**Gras**						
300310	Profileren en inzaaien gras	31,45	are	€	25,00	€	786,13
	Totaal gras			**€**	**786,13**		
	Benoemde directe bouwkosten					**€**	**105.975**
NTD031	Nader te detailleren bouwkosten	15,0%		€	105.975	€	15.896
	Directe bouwkosten					**€**	**121.871**
IK036	Eenmalige kosten	2,0%		€	121.871	€	2.437
IK037	Algemene bouwplaatskosten	1,0%		€	121.871	€	1.219
IK039	Uitvoeringskosten	6,0%		€	121.871	€	7.312
IK0310	Algemene kosten	8,0%		€	132.840	€	10.627
IK0311	Winst	3,0%		€	143.467	€	4.304
IK0312	Risico	2,0%		€	143.467	€	2.869
	Indirecte bouwkosten	**24%**				**€**	**28.769**
VZBK	**Voorziene bouwkosten**					**€**	**150.640**
RBK033	Niet benoemd objectrisico bouwkosten	15,0%		€	150.640	€	22.596
RBK	**Risico's bouwkosten**	**15%**				**€**	**22.596**
BK03	**Bouwkosten Locatie west: voorland klei met achterland**					**€**	**173.236**

5 | 12 Witteveen+Bos | | Ongecontr.

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
(Deel)raming:	Locatie west: voorland zand met achterland	Status:	Ongecont	Auteur:	0

code post	omschrijving post	hoeveelheid	eenheid		prijs		totaal
4							
	INVESTERINGSKOSTEN	95	m				
20	**Grondwerk**						
200420	Klei leveren en verwerken in kern	3.496,00	m3	€	20,00	€	69.920,00
200430	Klei leveren en verwerken in afdekking (categorie 2), dik 0,5-2,3 m	1.567,50	m3	€	22,50	€	35.268,75
	Totaal grondwerk			**€**	**105.188,75**		
30	**Gras**						
300410	Profileren en inzaaien gras	31,45	are	€	25,00	€	786,13
	Totaal gras			**€**	**786,13**		
	Benoemde directe bouwkosten					**€**	**105.975**
NTD041	Nader te detailleren bouwkosten	15,0%		€	105.975	€	15.896
	Directe bouwkosten					**€**	**121.871**
IK046	Eenmalige kosten	2,0%		€	121.871	€	2.437
IK047	Algemene bouwplaatskosten	1,0%		€	121.871	€	1.219
IK049	Uitvoeringskosten	6,0%		€	121.871	€	7.312
IK0410	Algemene kosten	8,0%		€	132.840	€	10.627
IK0411	Winst	3,0%		€	143.467	€	4.304
IK0412	Risico	2,0%		€	143.467	€	2.869
	Indirecte bouwkosten	24%				**€**	**28.769**
VZBK	**Voorziene bouwkosten**					**€**	**150.640**
RBK043	Niet benoemd objectrisico bouwkosten	15,0%		€	150.640	€	22.596
RBK	**Risico's bouwkosten**	15%				**€**	**22.596**
BK04	**Bouwkosten Locatie west: voorland zand met achterland**					**€**	**173.236**

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
(Deel)raming:	Locatie zuid: Voorland klei	Status:	Ongecont	Auteur:	0

code post	omschrijving post	hoeveelheid	eenheid		prijs		totaal
5							
	INVESTERINGSKOSTEN	425	m				
20	**Grondwerk**						
200520	Klei leveren en verwerken in kern	8.500,00	m3	€	20,00	€	170.000,00
200530	Klei leveren en verwerken in afdekking (categorie 2), dik 0,5-2,3 m	9.945,00	m3	€	22,50	€	223.762,50
	Totaal grondwerk			**€**	**393.762,50**		
30	**Gras**						
300510	Profileren en inzaaien gras	124,53	are	€	25,00	€	3.113,13
	Totaal gras			**€**	**3.113,13**		
	Benoemde directe bouwkosten					**€**	**396.876**
NTD051	Nader te detailleren bouwkosten	15,0%		€	396.876	€	59.531
	Directe bouwkosten					**€**	**456.407**
IK056	Eenmalige kosten	2,0%		€	456.407	€	9.128
IK057	Algemene bouwplaatskosten	1,0%		€	456.407	€	4.564
IK059	Uitvoeringskosten	6,0%		€	456.407	€	27.384
IK0510	Algemene kosten	8,0%		€	497.484	€	39.799
IK0511	Winst	3,0%		€	537.282	€	16.118
IK0512	Risico	2,0%		€	537.282	€	10.746
	Indirecte bouwkosten	24%				**€**	**107.739**
VZBK	**Voorziene bouwkosten**					**€**	**564.146**
RBK053	Niet benoemd objectrisico bouwkosten	15,0%		€	564.146	€	84.622
RBK	**Risico's bouwkosten**	15%				**€**	**84.622**
BK05	**Bouwkosten Locatie zuid: Voorland klei**					**€**	**648.768**

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
(Deel)raming:	Locatie zuid: Voorland zand	Status:	Ongecont	Auteur:	0

code post	omschrijving post	hoeveelheid	eenheid		prijs		totaal
6							
	INVESTERINGSKOSTEN	425	m				
20	**Grondwerk**						
200610	Zand leveren en verwerken in kern	8.500,00	m3	€	12,50	€	106.250,00
200630	Klei leveren en verwerken in afdekking (categorie 2), dik 0,5-2,3 m	9.945,00	m3	€	22,50	€	223.762,50
	Totaal grondwerk			**€**	**330.012,50**		
30	**Gras**						
300610	Profileren en inzaaien gras	124,53	are	€	25,00	€	3.113,13
	Totaal gras			**€**	**3.113,13**		
	Benoemde directe bouwkosten					**€**	**333.126**
NTD061	Nader te detailleren bouwkosten	15,0%		€	333.126	€	49.969
	Directe bouwkosten					**€**	**383.094**
IK066	Eenmalige kosten	2,0%		€	383.094	€	7.662
IK067	Algemene bouwplaatskosten	1,0%		€	383.094	€	3.831
IK069	Uitvoeringskosten	6,0%		€	383.094	€	22.986
IK0610	Algemene kosten	8,0%		€	417.573	€	33.406
IK0611	Winst	3,0%		€	450.979	€	13.529
IK0612	Risico	2,0%		€	450.979	€	9.020
	Indirecte bouwkosten	24%				**€**	**90.433**
VZBK	**Voorziene bouwkosten**					**€**	**473.528**
RBK063	Niet benoemd objectrisico bouwkosten	15,0%		€	473.528	€	71.029
RBK	**Risico's bouwkosten**	15%				**€**	**71.029**
BK06	**Bouwkosten Locatie zuid: Voorland zand**					**€**	**544.557**

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
(Deel)raming:	Locatie zuid: Terrein klei	Status:	Ongecont	Auteur:	0

code post	omschrijving post	hoeveelheid	eenheid		prijs		totaal
7							
	INVESTERINGSKOSTEN	385	m				
20	**Grondwerk**						
200720	Klei leveren en verwerken in kern	1.251,25	m3	€	20,00	€	25.025,00
200730	Klei leveren en verwerken in afdekking (categorie 2), dik 0,5-2,3 m	2.271,50	m3	€	22,50	€	51.108,75
	Totaal grondwerk			**€**	**76.133,75**		
30	**Gras**						
300710	Profileren en inzaaien gras	45,05	are	€	25,00	€	1.126,13
	Totaal gras			**€**	**1.126,13**		
	Benoemde directe bouwkosten					**€**	**77.260**
NTD071	Nader te detailleren bouwkosten	15,0%		€	77.260	€	11.589
	Directe bouwkosten					**€**	**88.849**
IK076	Eenmalige kosten	2,0%		€	88.849	€	1.777
IK077	Algemene bouwplaatskosten	1,0%		€	88.849	€	888
IK079	Uitvoeringskosten	6,0%		€	88.849	€	5.331
IK0710	Algemene kosten	8,0%		€	96.845	€	7.748
IK0711	Winst	3,0%		€	104.593	€	3.138
IK0712	Risico	2,0%		€	104.593	€	2.092
	Indirecte bouwkosten	24%				**€**	**20.974**
VZBK	**Voorziene bouwkosten**					**€**	**109.823**
RBK073	Niet benoemd objectrisico bouwkosten	15,0%		€	109.823	€	16.473
RBK	**Risico's bouwkosten**	15%				**€**	**16.473**
BK07	**Bouwkosten Locatie zuid: Terrein klei**					**€**	**126.296**

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
(Deel)raming:	Locatie zuid: Terrein zand	Status:	Ongecont	Auteur:	0

code post	omschrijving post	hoeveelheid	eenheid		prijs		totaal
8							
	INVESTERINGSKOSTEN	385	m				
20	**Grondwerk**						
200820	Klei leveren en verwerken in kern	1.251,25	m3	€	20,00	€	25.025,00
200830	Klei leveren en verwerken in afdekking (categorie 2), dik 0,5-2,3 m	2.271,50	m3	€	22,50	€	51.108,75
	Totaal grondwerk			**€**	**76.133,75**		
30	**Gras**						
300810	Profileren en inzaaien gras	45,05	are	€	25,00	€	1.126,13
	Totaal gras			**€**	**1.126,13**		
	Benoemde directe bouwkosten					**€**	**77.260**
NTD081	Nader te detailleren bouwkosten	15,0%		€	77.260	€	11.589
	Directe bouwkosten					**€**	**88.849**
IK086	Eenmalige kosten	2,0%		€	88.849	€	1.777
IK087	Algemene bouwplaatskosten	1,0%		€	88.849	€	888
IK089	Uitvoeringskosten	6,0%		€	88.849	€	5.331
IK0810	Algemene kosten	8,0%		€	96.845	€	7.748
IK0811	Winst	3,0%		€	104.593	€	3.138
IK0812	Risico	2,0%		€	104.593	€	2.092
	Indirecte bouwkosten	24%				**€**	**20.974**
VZBK	**Voorziene bouwkosten**					**€**	**109.823**
RBK083	Niet benoemd objectrisico bouwkosten	15,0%		€	109.823	€	16.473
RBK	**Risico's bouwkosten**	15%				**€**	**16.473**
BK08	**Bouwkosten Locatie zuid: Terrein zand**					**€**	**126.296**

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
(Deel)raming:	Locatie west: Tussendijk klei	Status:	Ongecont	Auteur:	0

code post	omschrijving post	hoeveelheid	eenheid		prijs		totaal
9							
	INVESTERINGSKOSTEN	65	m				
20	**Grondwerk**						
200920	Klei leveren en verwerken in kern	211,25	m3	€	20,00	€	4.225,00
200930	Klei leveren en verwerken in afdekking (categorie 2), dik 0,5-2,3 m	383,50	m3	€	22,50	€	8.628,75
	Totaal grondwerk			**€**	**12.853,75**		
30	**Gras**						
300910	Profileren en inzaaien gras	7,61	are	€	25,00	€	190,13
	Totaal gras			**€**	**190,13**		
	Benoemde directe bouwkosten					**€**	**13.044**
NTD091	Nader te detailleren bouwkosten	15,0%		€	13.044	€	1.957
	Directe bouwkosten					**€**	**15.000**
IK096	Eenmalige kosten	2,0%		€	15.000	€	300
IK097	Algemene bouwplaatskosten	1,0%		€	15.000	€	150
IK099	Uitvoeringskosten	6,0%		€	15.000	€	900
IK0910	Algemene kosten	8,0%		€	16.350	€	1.308
IK0911	Winst	3,0%		€	17.659	€	530
IK0912	Risico	2,0%		€	17.659	€	353
	Indirecte bouwkosten	24%				**€**	**3.541**
VZBK	**Voorziene bouwkosten**					**€**	**18.541**
RBK093	Niet benoemd objectrisico bouwkosten	15,0%		€	18.541	€	2.781
RBK	**Risico's bouwkosten**	15%				**€**	**2.781**
BK09	**Bouwkosten Locatie west: Tussendijk klei**					**€**	**21.323**

Opdrachtgever:	Universiteit Twente	Prijspeil:	2016	Datum:	2-6-2016
Project:	Bachelor opdracht Ellen Daamen	Versie:	01	Projectcode:	
(Deel)raming:	Locatie west: Tussendijk zand	Status:	Ongecont	Auteur:	0

code post	omschrijving post	hoeveelheid	eenheid		prijs		totaal
10							
	INVESTERINGSKOSTEN	65	m				
20	**Grondwerk**						
201010	Zand leveren en verwerken in kern	211,25	m3	€	12,50	€	2.640,63
201030	Klei leveren en verwerken in afdekking (categorie 2), dik 0,5-2,3 m	383,50	m3	€	22,50	€	8.628,75
	Totaal grondwerk			**€**	**11.269,38**		
30	**Gras**						
301010	Profileren en inzaaien gras	7,61	are	€	25,00	€	190,13
	Totaal gras			**€**	**190,13**		
	Benoemde directe bouwkosten					**€**	**11.460**
NTD101	Nader te detailleren bouwkosten	15,0%		€	11.460	€	1.719
	Directe bouwkosten					**€**	**13.178**
IK106	Eenmalige kosten	2,0%		€	13.178	€	264
IK107	Algemene bouwplaatskosten	1,0%		€	13.178	€	132
IK109	Uitvoeringskosten	6,0%		€	13.178	€	791
IK1010	Algemene kosten	8,0%		€	14.364	€	1.149
IK1011	Winst	3,0%		€	15.514	€	465
IK1012	Risico	2,0%		€	15.514	€	310
	Indirecte bouwkosten	24%				**€**	**3.111**
VZBK	**Voorziene bouwkosten**					**€**	**16.289**
RBK103	Niet benoemd objectrisico bouwkosten	15,0%		€	16.289	€	2.443
RBK	**Risico's bouwkosten**	15%				**€**	**2.443**
BK10	**Bouwkosten Locatie west: Tussendijk zand**					**€**	**18.733**